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Mass, salt, and heat transportation across four latitude circles in the south Atlantic Ocean.

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THESIS

MASS, SALT, AND HEAT TRANSPORT ACROSS FOUR LATITUDE CIRCLES IN THE SOUTH ATLANTIC OCEAN

by

J. Robert Mason

December 1978

Thesis Advisor: G. H. Jung

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In this report classic dynamic height calculations were made from International Geophysical Year (1957-1958) and adjacent 1959 oceanographic data to obtain geostrophic currents and estimates of mass, salt, and heat transports in the South Atlantic Ocean. The cross sections extend from South America to Africa along the 8°S, 16°S, 24°S, and 32°S latitude lines, providing temperature and salinity data from the surface to near bottom.

A level of no motion was determined by establishing mass and salt continuity across each of the latitudinal cross sections. This level varied from 1100 meters at 8°S to 1270 meters at 32°S. It is approximated by the 27.57 sigma-t surface and corresponds closely to the boundary between the Antarctic Intermediate Water and the South Atlantic Deep Water masses.

The resulting meridional heat transport was then examined and compared with other estimates. Northward (equatorward) heat transports resulted at each latitude, which would seem to oppose the conventional view of the role of the ocean in the earth's heat budget as a means to transfer heat from equator to poles. However, the northward direction of the net absolute heat transport agrees with the consensus of previous work and is attributed to the warmer surface currents with a net northward transport dominating the cooler deeper currents and their net southward flow.

A general circulation pattern was developed from mass transport values for each of three layers of water: Upper, Intermediate, and Deep and Bottom Water. These derived circulation patterns are then compared to general descriptive circulation patterns found in the literature. General agreement was found with the notable exception of lacking a strong Brazil current in the surface and central waters. Vertical cross sections of velocity, mass, salt, and heat transport were contoured to examine the eddy field circulation pattern and further describe general circulation patterns.

Mass, Salt, and Heat Transport Across Four Latitude Circles in the South Atlantic Ocean

by

J. Robert Mason
Lieutenant, United States Navy
B.S., United States Naval Academy, 1972

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY AND OCEANOGRAPHY

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I. INTRODUCTION

For the total earth-atmosphere system, the amount of heat received from the sun at the upper boundary of the system must, in the long term average, equal closely the amount of heat lost by reflection and radiation to space. This approximate balance must exist, since observed short term changes in the mean annual temperature of the atmosphere and oceans are small enough to be neglected. Therefore, over a time period of several years, an energy balance may be assumed and the short wave radiation absorbed by the land, the oceans, and the atmosphere is considered balanced by the long wave radiation to space from the entire system. Part of the arriving energy is transformed into the kinetic energy which drives ocean and atmosphere circulations.

The arriving short wave radiation does not strike the earth uniformly. Due to the geometry of the earth's orbit, the lower latitudes receive more short wave energy than is lost by long wave radiation; at higher latitudes the reverse is true. There is consequently a net gain of heat in the tropics and a net loss in the higher latitudes. Since, for a given latitude the mean annual temperatures remain unchanged, there must be energy transport from lower to higher latitudes. The air-ocean circulation systems are primarily responsible for this redistribution of energy between the latitudes.

In the early part of this century it was popularly assumed that the transport of heat by oceanic currents was small or negligible when compared with that transported by the atmosphere. Bjerknes _et al._ (1936) and Sverdrup _et al._ (1942) proceeded under this assumption, but provided

the caveat that the question had not been thoroughly examined.

In examining the question further, Jung, in 1952, proposed that the oceans could indeed provide a significant contribution to the heat balance of the earth. Previous works considered only the horizontal surface current systems in heat transport studies whereas Jung proposed closed vertical circulations in the north-south direction which could transport significantly large amounts of heat between equator and pole. Jung's hypothesis was extended in a 1955 study of geostrophic currents in the North Atlantic derived from the METEOR Expedition data which resulted in computations of significant oceanic heat transport meridionally. Other studies have verified further the importance of ocean circulations in the transport of energy. Budyko (1956), Sverdrup (1957), Bryan (1962), Sellers (1965), Emig (1967), Vander Haar and Oort (1973), and Bennett (1978) all estimated significant meridional heat transports in various oceans.

This study attempts a nearly synoptic look at four latitudinal sections in the South Atlantic Ocean between 8°S and 32°S using temperature and salinity data from the International Geophysical Year (1957-1958) and 1959. A computer program developed by Greeson (1974) is used to calculate volume, mass, salt, and heat transports across the various latitude sections. The computer program was modified to include previously hand calculated transports in areas below the deepest sounding and to identify water masses by salinity and temperature criteria. By requiring mass and salt continuity across each section conclusions were drawn concerning the level of no motion, general geostrophic circulation, and net heat flux characteristics of the South Atlantic Ocean during this period.

II. BACKGROUND

A. ENERGY TRANSPORT

The redistribution of energy in the earth-atmosphere system is accomplished primarily by advection of sensible heat within the ocean's current systems and transport of latent and sensible heat within atmospheric circulations. Ordinarily, the processes of conduction throughout continental land masses and through the ocean floor are ignored. Whether the ocean or the atmosphere is the dominant mechanism for energy transport has been a source of debate over the past century.

Maury (1856) and Ferrel (1890) maintained that the ocean was the chief source of energy transport meridionally because even though oceanic velocities are an order of magnitude smaller than atmospheric velocities and the atmosphere has a greater volume exchange than the ocean, the mass exchange and heat capacity of the ocean is greater. An opposing view was held by Bjerknes et al. (1933) and Sverdrup et al. (1942), both of whom assumed that the transport of energy from lower to higher latitudes by ocean currents is negligible when compared to the atmospheric contribution for worldwide averages, but can be of importance locally in certain regions. A study by Angstrom (1925) indicated a rough equality between ocean and atmospheric contributions to energy transport. Jung (1952, 1955) showed that meridional transport by the oceans, while not as large as the atmosphere, was not insignificant. Neumann et al. (1966) stresses the importance of the ocean, particularly in transferring energy to the region between 20°N and 40°N wherein it is made available to the atmosphere in the form of latent heat for further northward transport.

This study attempts a quantitative analysis of the ocean transports of mass, salt, and heat across vertical cross sections of the ocean in the South Atlantic Ocean at four latitudes.

B. DETERMINATION OF THE LEVEL OF NO MOTION

The procedure for computing transports in this study uses the dynamic method for calculating relative geostrophic velocities between oceanographic station pairs. The procedure is described in Section IV-B. In order to obtain quantitative estimates of the transports, however, the relative geostrophic velocities calculated by the dynamic method must be converted to absolute velocities. To accomplish this, a level of no meridional motion was required against which the relative velocities were referenced and thereby converted to absolute velocities.

Since current measurements are not taken along with the standard oceanographic station cast, indirect methods of determining the level of no motion have been developed over the past 60 years. A comprehensive summary of these methods is found in Sherfessee (1978) and Baker (1978) and includes descriptions of techniques developed by Jacobsen (1916), Parr (1938), Hidaka (1949), Defant (1941), Sverdrup et al. (1942), Stommel (1956), and Stommel and Schott (1977).

The method used to determine the level of no motion in this study was that from Sverdrup et al. (1942). The method entails imposing the requirement of mass and salt continuity across a given latitude section that extends completely across an ocean basin. The level of no motion is placed at the depth where the transport above the reference level is equal to and opposite to the transport below the reference level. This method requires data across an entire cross section of the ocean and

from the surface to the near bottom. This method proved to be the most reasonable for the comprehensive data used herein.

III. STATEMENT OF THE PROBLEM

The objectives of this study were sixfold: (1) to add to an existing computer program,which computes ocean transports through a vertical cross section, a subroutine which automatically classifies the water masses and sums their transport contributions by individual water mass type; (2) to modify the computer program to include in the transport calculations the cross sectional areas below the deepest sounding adjacent to the bottom whose effects previously were hand calculated; (3) to determine quantitatively the level of no motion in the South Atlantic such that the net mass and salt transport across each of the four sections is approximately zero; (4) to use the resulting mass transport to compare and describe the general circulation of the South Atlantic for Upper, Intermediate, and Deep and Bottom Water layers; (5) to compute the transport of sensible heat from the selected vertical cross sections, and (6) to estimate eddy activity by examining eddy patterns revealed in vertical cross sections of velocity and mass, salt, and heat transport which were contoured by the computer.

IV. PROCEDURE

A. DATA SOURCE

To apply the classic method of determining dynamic depths in the ocean, detailed temperature and salinity observations at known geometric depths below the actual sea surface were required for a given time period. In practice, simultaneous observations are not available, especially for an area the size of the South Atlantic Ocean, but it may be assumed that time changes in the pressure distribution are so small that observations taken within a given time frame may be considered synoptic. This is the assumption most often made in studies of broad oceanic circulations, especially prior to the satellite era.

The most comprehensive set of data meeting these criteria was found in Atlantic Ocean Atlas published by F. C. Fuglister in 1960. It is a compendium of data taken as part of International Geophysical Year (IGY, 1957-1958). To obtain these data, the classic oceanographic station measurements were carried out involving serial observations from surface to near bottom using Nansen bottles and reversing thermometers for temperature and salinity information. Data for the South Atlantic are in transects at four latitudes extending from South America to Africa with stations at roughly one degree intervals. The data were collected between March 1957 and June 1959. Table I shows additional information on these latitudinal cross sections.

Figure 1 shows the tracks along which the data were taken. Although the data were collected over slightly more than a two-year time period, they are considered synoptic for the purpose of studying the general circulation patterns.

TABLE I

OCEANOGRAPHIC STATION DATA

Average Latitude	Vessel	Station Numbers	Dates	Tracks
8°15' S	Crawford	86-92 94-120	March 1-22, 1957	Brazil to Angola
15°45' S	Crawford	121-153	April 1-22, 1957	Brazil to Angola
24°15' S	Crawford	416-458	October 2-26, 1958	Brazil to Southwest Africa
32°30' S	Atlantis	5798 5806-5843	April 11, 1959 April 26 - June 3, 1959	Brazil to Union of South Africa

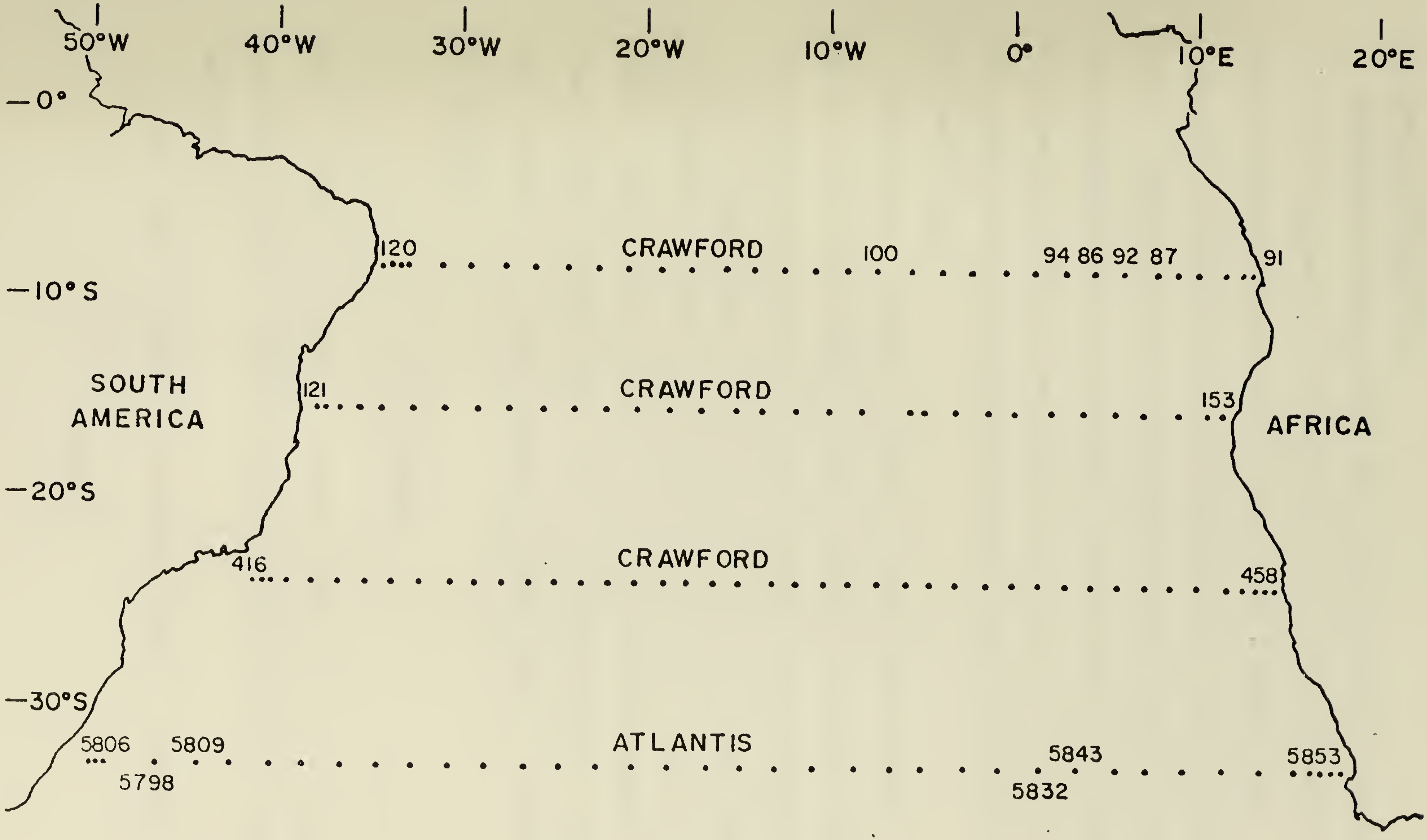


Figure 1. Chart of the Tracks and Station Numbers for Research Vessels Crawford and Atlantis during March 1957-June 1959.

B. COMPUTING TRANSPORTS

Transports of volume, mass, salt, and heat across a vertical cross section were computed using velocities derived by the Helland-Hansen formula [equation (4)] and the procedure from Sverdrup et al. (1942). In general, the method consists of application of the geostrophic approximation. Since the vertical shear of geostrophic velocity is proportional to the horizontal density gradient, a relative velocity profile may be calculated by assuming or measuring a velocity at one level and then vertically integrating measured horizontal density gradients converted to dynamic heights.

Specifically, a computer program was used from a master's thesis by Greeson (1974) which computed dynamic heights for standard depths at each ocean station by the Sverdrup procedure in the following manner.

The IGY temperature and salinity data taken at various depths were interpolated to standard depths using a combination linear and parabolic scheme. Then specific volume and the specific volume anomaly were computed for each standard depth. Next, an average specific volume anomaly for the center of the layer between standard depths is calculated using the equation:

$$\bar{\delta} = \frac{\delta_z + \delta_{(z+\Delta z)}}{2} , \tag{1}$$

where $\bar{\delta}$ is the average specific volume anomaly, and δ_z and $\delta_{(z+\Delta z)}$ are the computed specific volume anomalies at standard depths z and $z+\Delta z$ respectively.

Dynamic height difference, ΔD, for each layer is computed by:

$$\Delta D = \bar{\delta}[z-(z+\Delta z)] . \tag{2}$$

A vertical summation is made to obtain the total dynamic height of each station relative to the sea surface:

$$\sum_{o}^{z} \Delta D = D \, . \qquad (3)$$

Next, another subroutine is employed to compute L, the distance between each station pair as a function of latitude and longitude.

Geostrophic relative velocity differences at a location midway between each station pair were calculated for each standard depth using the Helland-Hansen equation:

$$v_1 - v_2 = \frac{10}{fL} (D_A - D_B) \qquad (4)$$

where v_1 and v_2 are the velocities at standard depths 1 and 2, D_A and D_B are the dynamic heights of the two stations, and f is the coriolis parameter.

The ocean surface was considered a geopotentially level surface with zero inclination between the pressure surface and the level surface for the purpose of calculating these relative velocities.

In order to convert from relative to absolute velocities, some criterion was required by which to establish the actual surface which has zero inclination, and thus, zero velocity. This surface is the level of no motion discussed in Section II. The method used in this study to determine that depth was simply to impose the requirement that the resulting net mass transport and net salt transport across the entire latitude sections of ocean be zero when based on the selected reference level:

$$\int \rho_s v_{n_s} \, do = 0 \qquad (5)$$

$$\int \rho_s S v_{n_s} \, do = 0$$

where S is salinity in parts per thousand and v_n is the velocity component perpendicular to the cross section.

The procedure followed was experimentally to vary the depth of the level of no motion in the computer program until the total net mass and salt balances across the sections were as small as could be obtained. The velocities for the remaining standard depths computed relative to this level of no motion were then considered absolute. The velocities thus obtained apply to a point midway between each station for each standard depth.

From these absolute velocities, transports of volume, mass, salt, and heat for the cross sectional area between the station pairs were next calculated for each layer between the standard depths. The velocities were available at the midpoints between the stations; values of density, salinity and temperature were interpolated for each standard depth.

To obtain a value for velocity, density, salinity, and temperature representative of the entire cross sectional area of the layer between the two stations an averaging process was performed to arrive at a central value for each parameter. The averaging process used by the computer program is illustrated in Figure 2.

These central values and the cross sectional area of the layer are used to compute the transports. The product of area, velocity, and density gives mass transport, which is then multiplied by the salinity and temperature, respectively, to obtain heat transport and salt transport.

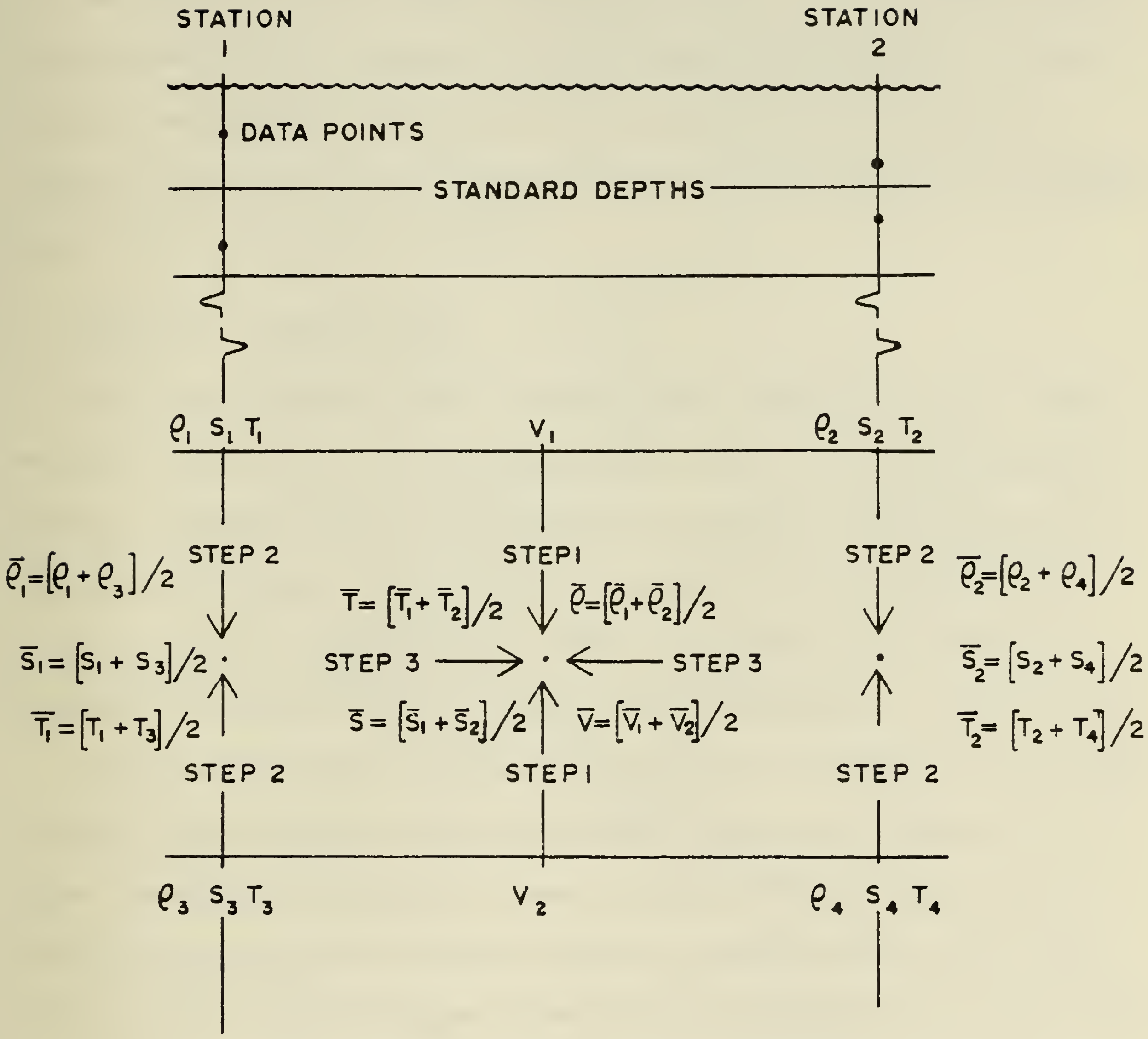


Figure 2. Illustration of the averaging process used to obtain a central mean value for velocity, density, salinity, and temperature for the rectangular cross-sectional area.

Mass, salt, and heat transports are summed in the vertical for each station pair and also in the horizontal for each layer.

Due to the procedures for data interpolation techniques and limitations in the accuracy of the computer, it was impossible to obtain exact zero mass and salt fluxes simultaneously for a single level of no motion. For the purposes of this study, mass balance was considered the primary criterion and salt an important, although secondary, balance consideration for continuity. Once mass and salt continuity was achieved as closely as possible, for the entire section, the corresponding heat transport for the section was recorded.

C. BOTTOM AREA CONTRIBUTIONS

The method described above determines the transports for the cross-sectional area down to the greatest common depths for each station pair. Figures 3 through 6 show the area below the greatest common depths which also must be included. In addition, an estimate must be made for the peripheral areas between the last station on either end of the section and land. An estimate for the latter will be discussed in Section IV-D.

The existing computer program was modified to account for the effects of these areas adjacent to the bottom which in the past were hand calculated. Bathymetric profiles for each latitude section were provided by Woods Hole Oceanographic Institution and the cross-sectional area between the ocean floor and the deepest common depth was measured for each station pair (the near-bottom area). Next, a linear decrease in velocity was assumed from the deepest common level to a zero velocity at the ocean floor; that is, a value of one-half the deepest calculated absolute velocity was used as the average velocity value for each area. Mass transport across the near-bottom area was found by multiplying this velocity by the

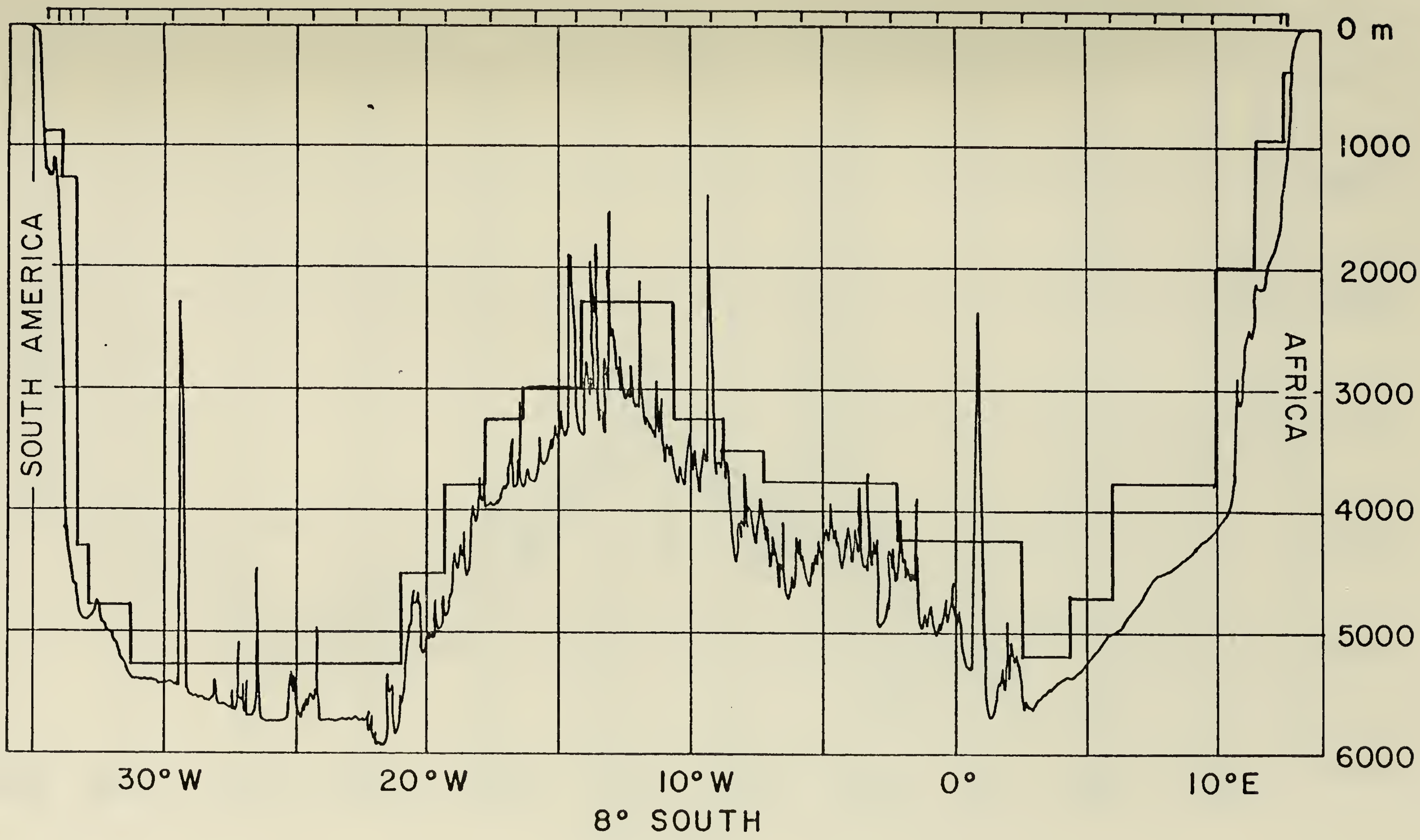


Figure 3. Bottom Peripheral Areas: 8°S Latitude Section.

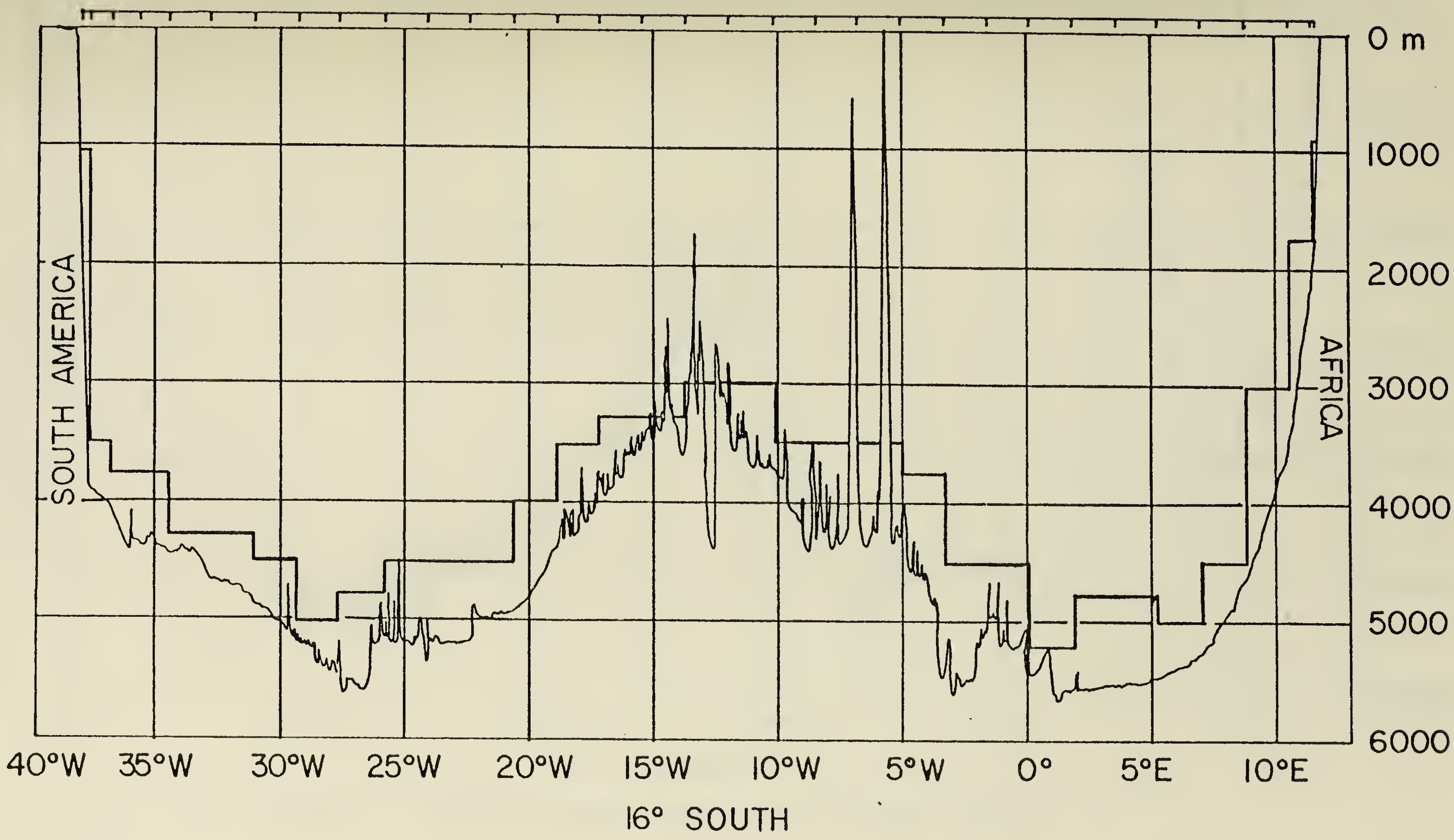


Figure 4. Bottom Peripheral Areas: 16°S Latitude Section.

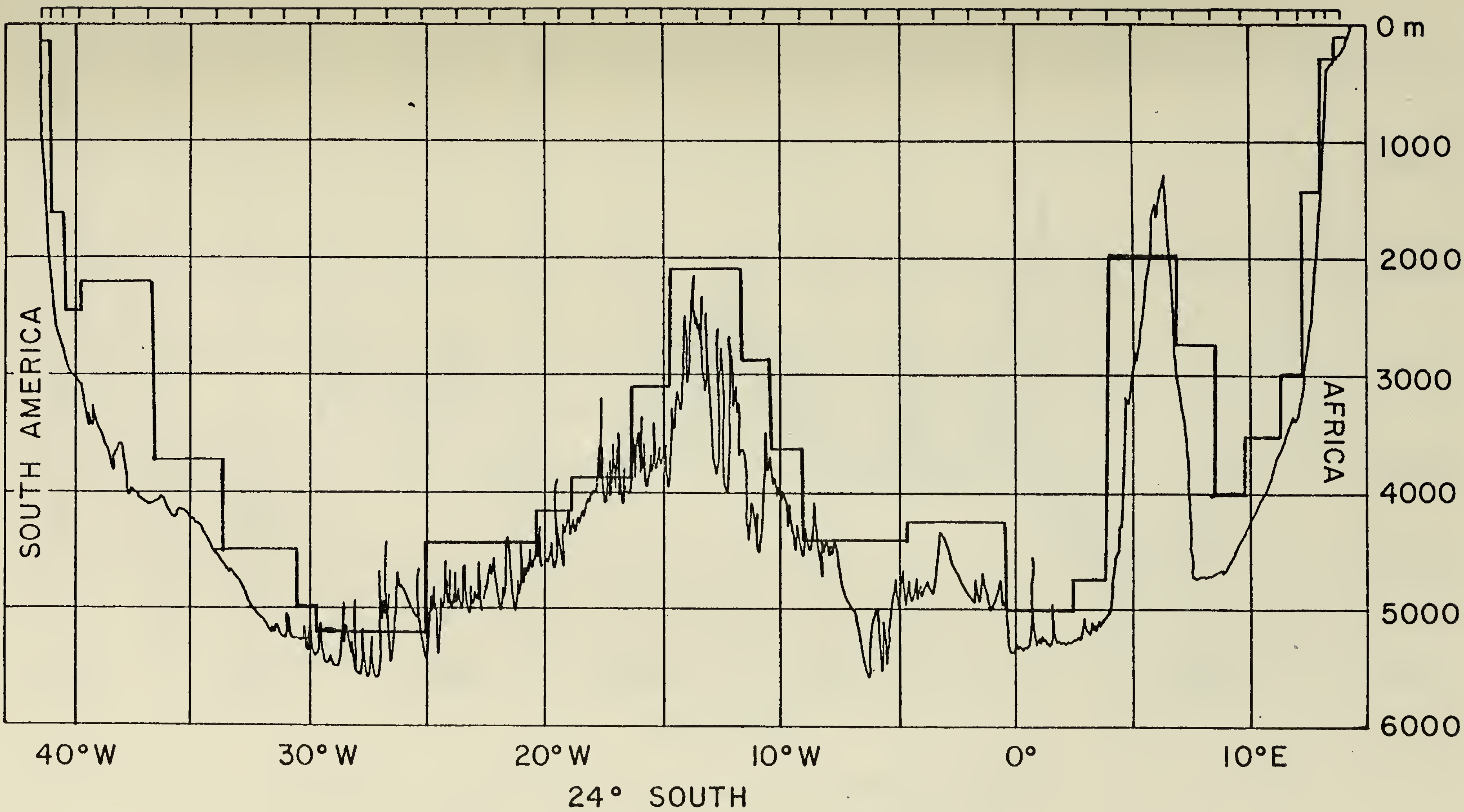


Figure 5. Bottom Peripheral Areas: 24°S Latitude Section.

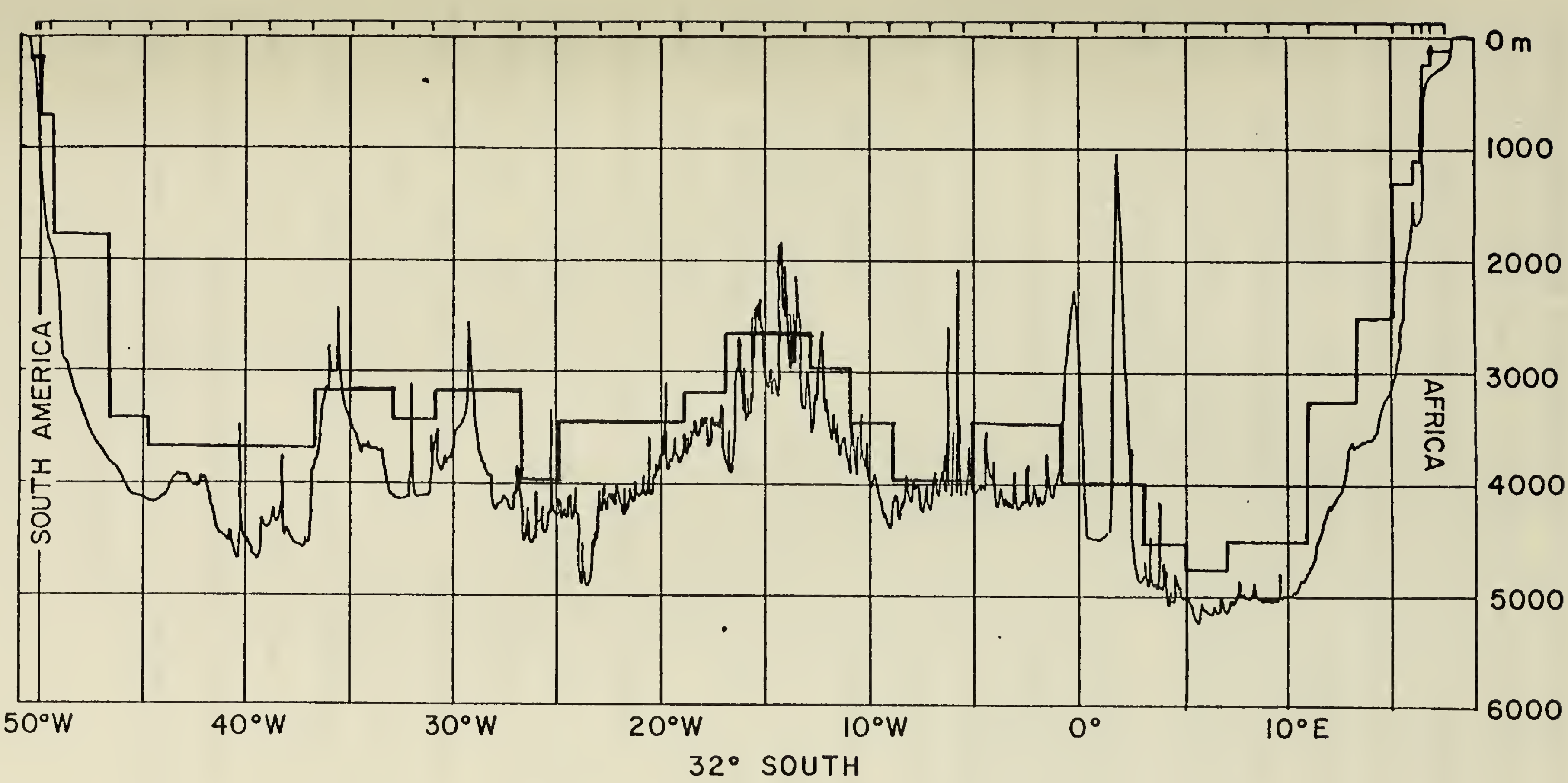


Figure 6. Bottom Peripheral Areas: 32°S Latitude Section.

deepest interpolated mean density and the near-bottom area. The mass transport was multiplied by the deepest average temperature and salinity values to find the corresponding heat and salt transports. The modified program then automatically added these results to the respective transports for the station pair. Consequently, these near-bottom areas are taken into consideration automatically during the search for the level of no motion for which net mass and salt fluxes across the entire latitude section must approach zero.

One potential problem with the method described above is in the accounting for the proper direction of the Antarctic Bottom Water. No Antarctic Bottom Water was identified from the oceanographic data, not because it was not present, but because the Nansen cast did not extend deep enough to sample it. Consequently, the deepest sampled water in the deep ocean stations is always South Atlantic Deep Water, which usually flows southward (poleward). By the method described above, the water below the deepest sounding is assigned a velocity of one half the average velocity at the deepest sounding. Therefore, the direction assigned to the water in the area adjacent to the bottom is usually southward also. The usually northward transports of the Antarctic Bottom Water may be missed entirely by this technique.

The cross-sectional area through which Antarctic Bottom Water flows is small by comparison to the remaining cross section, but not insignificant. A study by Greeson (1974) showed that the bottom peripheral area amounted to approximately ten percent of the total cross-sectional area, with some unknown portion of this area being attributed to the flow region of the Antarctic Bottom Water.

A volume transport of three million m^3/sec is estimated for Antarctic Bottom Water flowing northward across 30°S by Sverdrup et al. (1942). Even smaller values would be expected for Antarctic Bottom Water at lower latitudes. These values are considered negligible when compared with typical transports for even a single station pair in the cross section. Consequently, any bias in transports caused by not detecting the Antarctic Bottom Water in the Nansen casts was considered negligible.

D. ESTIMATING TRANSPORTS FOR THE PERIPHERAL AREAS ADJACENT TO LAND

The portion of the cross-sectional area as yet not accounted for was that of the peripheral areas between the last station on either end of the section and land. Values of mass, salt, and heat transport for these peripheral zones were calculated as follows.

The transport (volume, mass, salt, and heat) within each standard layer in the peripheral zone was considered to be a fraction of the transport for the same layer in the first station pair nearest the end. The fraction was determined by assuming a linear decrease in current velocities toward shore for each horizontal layer, with zero velocity at the beach. Therefore, a value of one-half the layer volume transport for the first station pair was considered representative for the peripheral zone. Next, this estimate was corrected for the difference in cross-sectional area between the first station pair and the periphery by multiplying by the ratio of areas, layer by layer. Finally, the layers were summed to obtain total transports for the peripheral zone.

This method was devised to take advantage of the observed salinity and temperature data for each layer. For purposes of comparison the results were qualitatively evaluated against climatological temperature and salinity data obtained from Fleet Numerical Weather Central's

"Hydroclimatological Data Retrieval Program" (HYDAT) and current velocities from pilot charts. The statistics from HYDAT were consistent with the data of this study. but were not detailed enough for the layer-by-layer estimates obtained by the ratio method. Several of the peripheral areas had negligible cross-sectional areas and their contribution to transport was discarded.

To demonstrate the procedure described above, transports were calculated for a single end zone. Figure 7 illustrates the geometry of the problem and Table II lists the results. As can be seen from Table II, the mass, salt, and heat transports for each 50-meter layer of the adjacent station pairs were multiplied by the ratio of lengths and then by one-half to account for the assumed linear decrease in velocity toward shore.

Table III shows the results for each end zone, the cumulative contribution of the two end zones for each latitude, and a grand total net result for all eight peripheral areas. For the purpose of evaluating total net transports the results were considered negligible since compensating for even the largest value obtained changed the level of no motion across the latitude section by less than one meter.

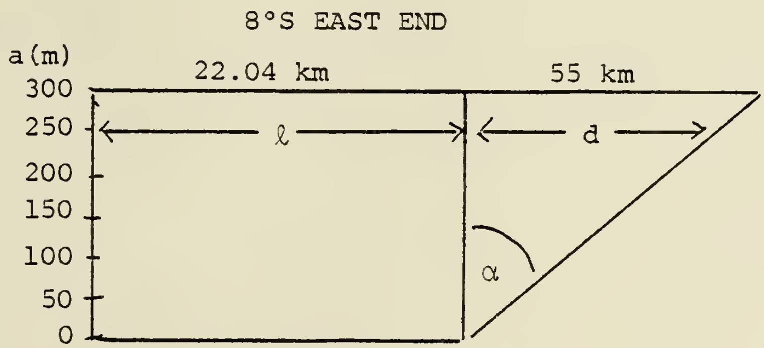


Figure 7. Illustration of the technique for estimating the transports of mass, salt, and heat in the peripheral zones; $d = a \tan\alpha$.

TABLE II

ESTIMATED TRANSPORTS OF MASS, SALT, AND HEAT IN THE PERIPHERAL ZONES AT 8°S, EAST END

a(km)	R[1]	(.5R) x Mass (g/sec)	(.5R) x Salt (g/sec)	(.5R) x Heat (cal/sec)
.300				
	2.4955	-.22435[2]	-7.64393[3]	-66.92056[2]
.250				
	2.0796	.02946	1.04579	8.61866
.200				
	1.6636	.08013	2.85529	23.18796
.150				
	1.2477	.02327	0.81847	1.57821
.100				
	0.8318	.00368	0.12073	1.05214
.050				
	0.4159	.00099	-.03458	-.28034
.000				
	0.0	0.0	0.0	0.0
Total		-.08880	-2.82923	-32.76393

[1] R is the ratio of lengths for each 50 meter layer;

$d = a \tan \alpha$;

$R = d/l = a \tan \alpha / l$.

[2] (all values times 10^{12})

[3] (all values times 10^{9})

TABLE III

ESTIMATES OF MASS, SALT, AND HEAT TRANSPORTS
FOR PERIPHERAL AREAS AT EACH LATITUDE

Latitude		West End	East End	Total
8°S	Mass[1]	- .06432	- .08880	- .15312
	Salt[2]	- 3.41850	- 2.82923	- 6.24773
	Heat[3]	-27.66394	-32.76393	-60.42787
16°S	Mass	- .09711	.23887	.14176
	Salt	- 3.53711	8.49962	4.96251
	Heat	-29.37412	69.57869	40.20457
24°S	Mass			
	Salt	Negligible	Negligible	Negligible
	Heat			
32°S	Mass		- .16417	- .16417
	Salt	Negligible	- 5.76357	- 5.76357
	Heat		-47.13947	-47.13947
Grand Total	Mass	- .17553		
	Salt	- 7.04879		
	Heat	-67.36277		

1 g/sec x 10^{12}

2 g/sec x 10^{9}

3 cal/sec x 10^{12}

E. IDENTIFICATION OF WATER MASSES

An additional modification of the existing computer program was effected in order to provide automatic identification of water masses in the South Atlantic Ocean based on salinity, temperature, and depth criteria and additionally to identify and sum mass, salt, and heat transports according to water mass type.

The criteria used to identify the various water masses in the South Atlantic Ocean were found in Defant (1961), Sverdrup et al. (1942), Williams et al. (1973), and Bialek (1967). The specific temperature and salinity for each water mass used in this study were extracted from these works and expanded somewhat to include the transition waters between each water mass type. Table IV lists the temperature and salinity values used in this study to identify the water masses in the South Atlantic Ocean.

No specifications for surface water were listed in the literature; thus, a temperature criterion was established to delineate the mixed layer adjacent to the sea surface.

Figures 8 through 11 depict the various water masses found in the South Atlantic and the level of no motion through the cross section. No Sub-Antarctic Water, Antarctic Circumpolar Water or Antarctic Bottom Water was found. It is reasonable to assume that Sub-Antarctic Water and Antarctic Circumpolar Water were not identified due to the low latitude of the sections. Antarctic Bottom Water, however, was undoubtedly present but went undetected because the data available did not extend deep enough to sample it. Rather than arbitrarily specifying that any water below the last sounding was Antarctic Bottom Water, this water was instead assigned to a Deep and Bottom Water category collectively.

TABLE IV

TEMPERATURE AND SALINITY CRITERIA FOR WATER MASS IDENTIFICATION IN THE SOUTH ATLANTIC OCEAN

Watermass	Temperature (°C)	Salinity (o/oo)	Reference
Antarctic Bottom Water	< 0	34.65 to 34.67	Defant
Antarctic Circumpolar Water	0-2.5	34.68 to 34.80	All
Sub-Antarctic Water	7.0-9.0	34.10 to 34.68	Defant
South Atlantic Deep Water	7.0-9.0	34.70 to 34.97	Defant
Antarctic Intermediate	2.8-7.0	33.80 to 34.71	Sverdrup and Defant
South Atlantic Central	5.0-18.0	34.45 to 36.10	Williams
Surface	> 18.0		

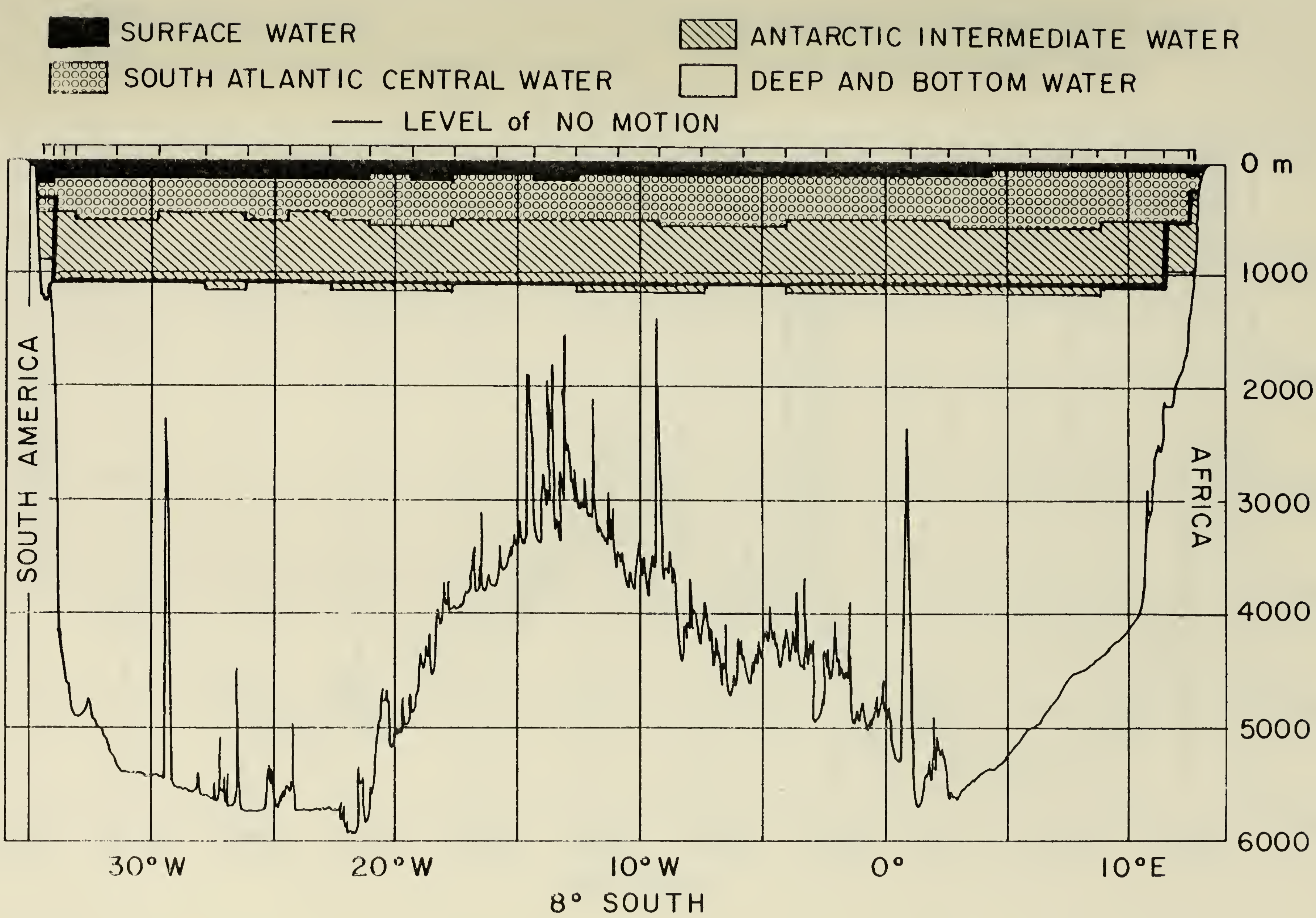


Figure 8. Water Masses and Level of no Motion: 8°S.

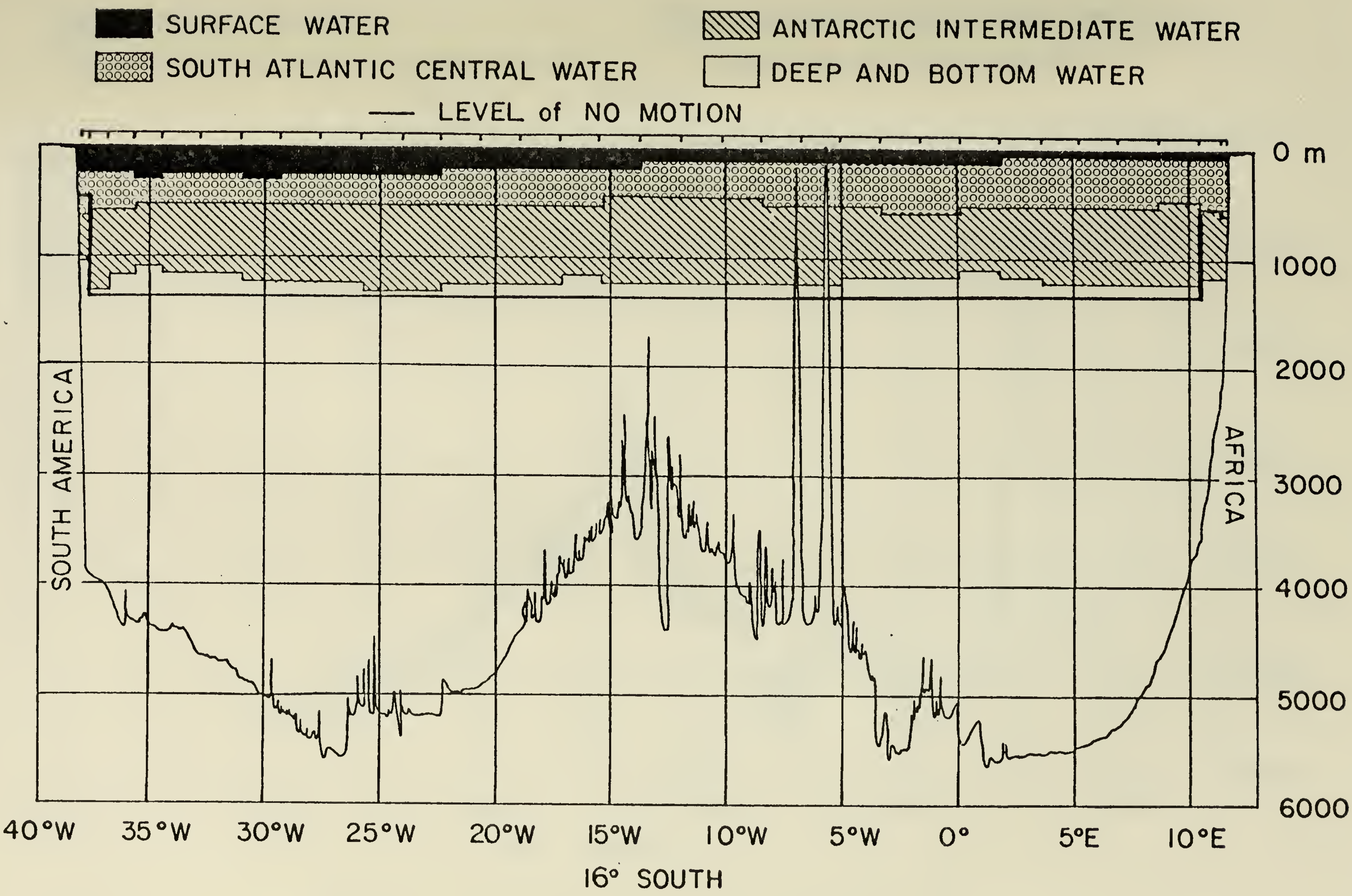


Figure 9. Water Masses and Level of no Motion: 16°S.

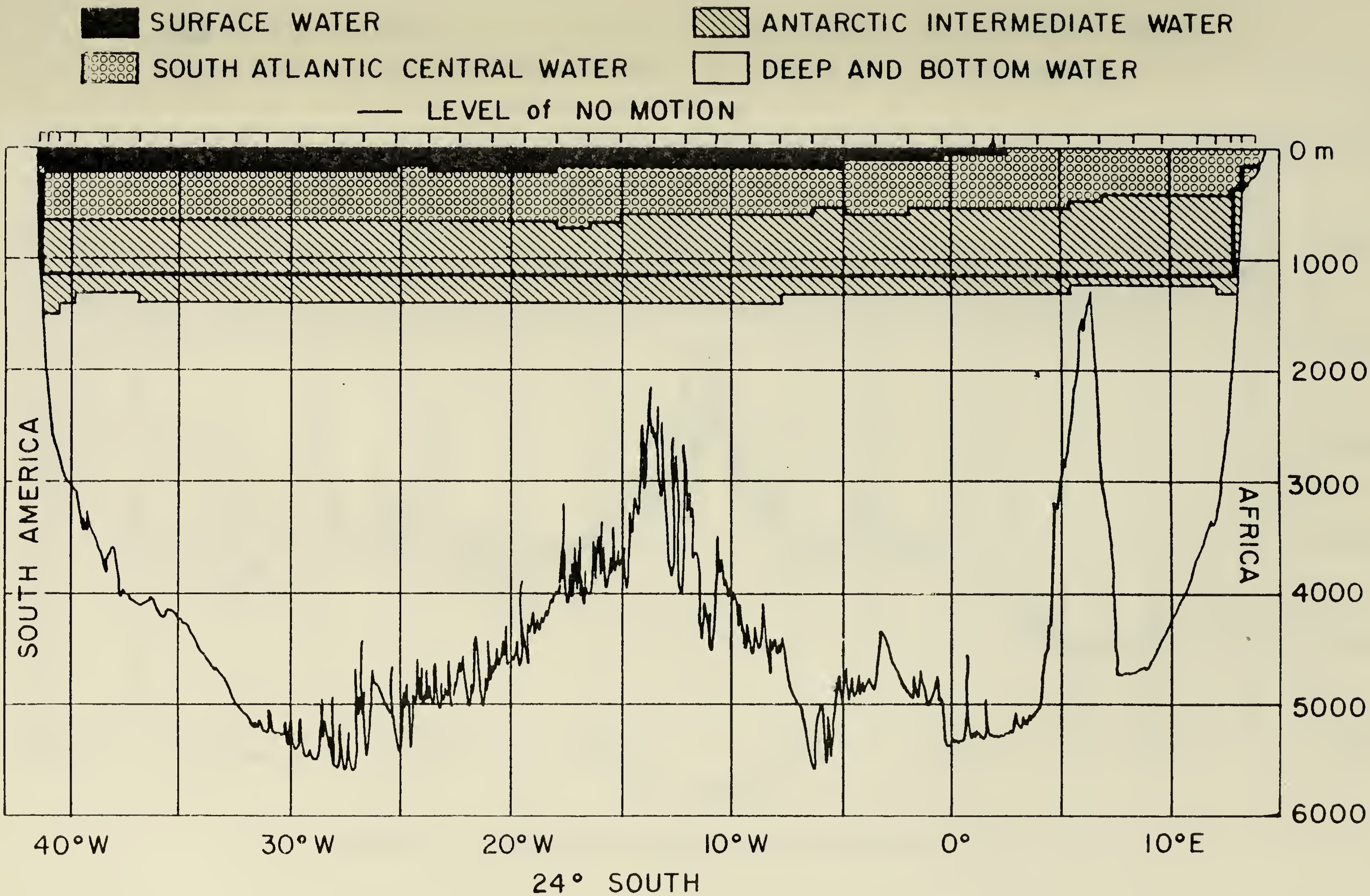


Figure 10. Water Masses and Level of no Motion: 24°S.

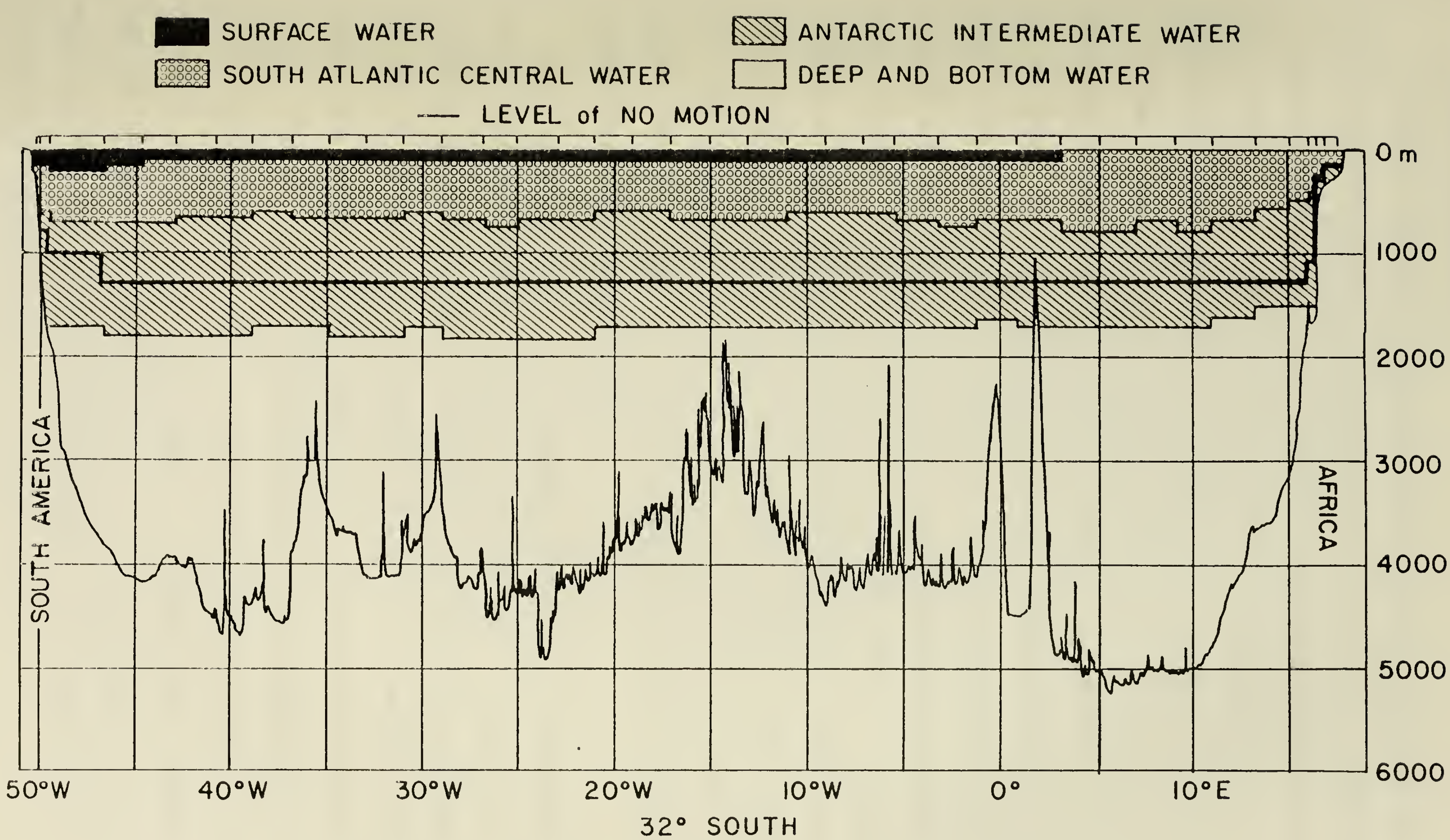


Figure 11. Water Masses and Level of no Motion: 32°S.

F. GENERAL CIRCULATION

In order to study the general circulation of the South Atlantic Ocean the mass transports were separated into three layers: Upper Water (consisting of Surface and Central Waters), Intermediate Water and Deep and Bottom Water. The absolute mass transport for each layer and for each station pair was computed and recorded on the chart at the proper location.

These integrated mass transport figures for each layer at each station pair were combined into a composite value for increments of five degrees of latitude. Figures 12 through 14 give a graphical idea of the net transports involved for each increment. A general circulation pattern was then devised for the Upper, Intermediate, and Deep and Bottom Waters consistent with net mass transports across each latitude circle. To provide continuity of mass and to match observed circulations, series of cyclonic and anticyclonic eddies were constructed. Robinson (1976) reports extensive mid-ocean eddy activity at all scales in the ocean from the sea surface to the bottom thus lending credence to the eddy concept used here in approximating the circulation.

Areas of convergence and divergence are shown as symbols for gain and loss to the layers of water depicted in Figures 17 through 19. These indicate the general areas of upwelling and downwelling required for continuity in the vertical. To further identify the general circulation and examine it in the vertical, geostrophic current velocities and transports of mass, salt, and heat were interpolated in the computer to a rectangular matrix representing a vertical cross section of the ocean and then contoured at various levels by a computer subroutine named CONTUR. An attempt was made to describe quantitatively by size and frequency distribution any eddy features identified by this procedure. The results of this effort are found in Appendix III.

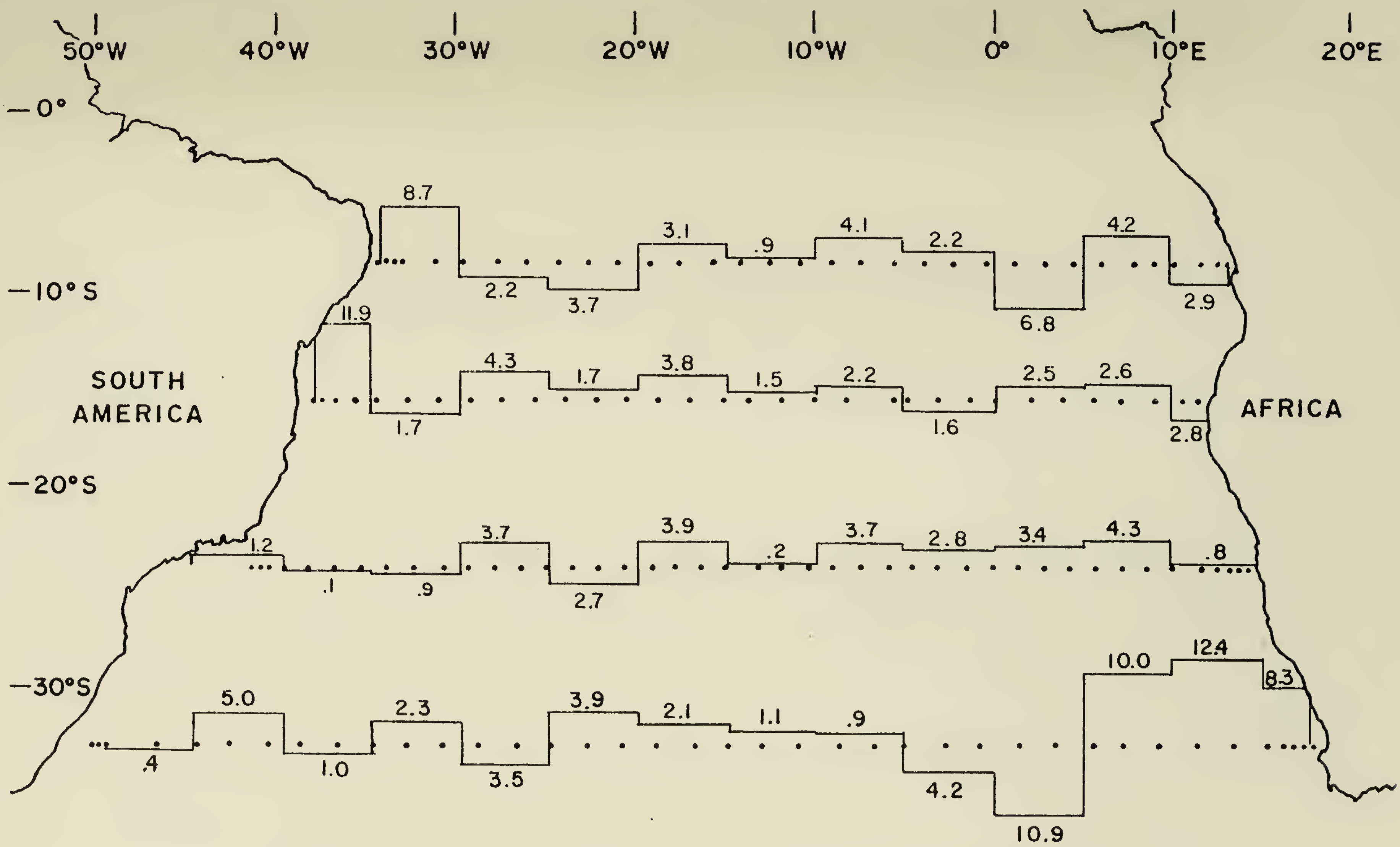


Figure 12. Integrated Mass Transports for Five Degree Increments: Upper Water; (Fig. 17 shows circulation pattern).

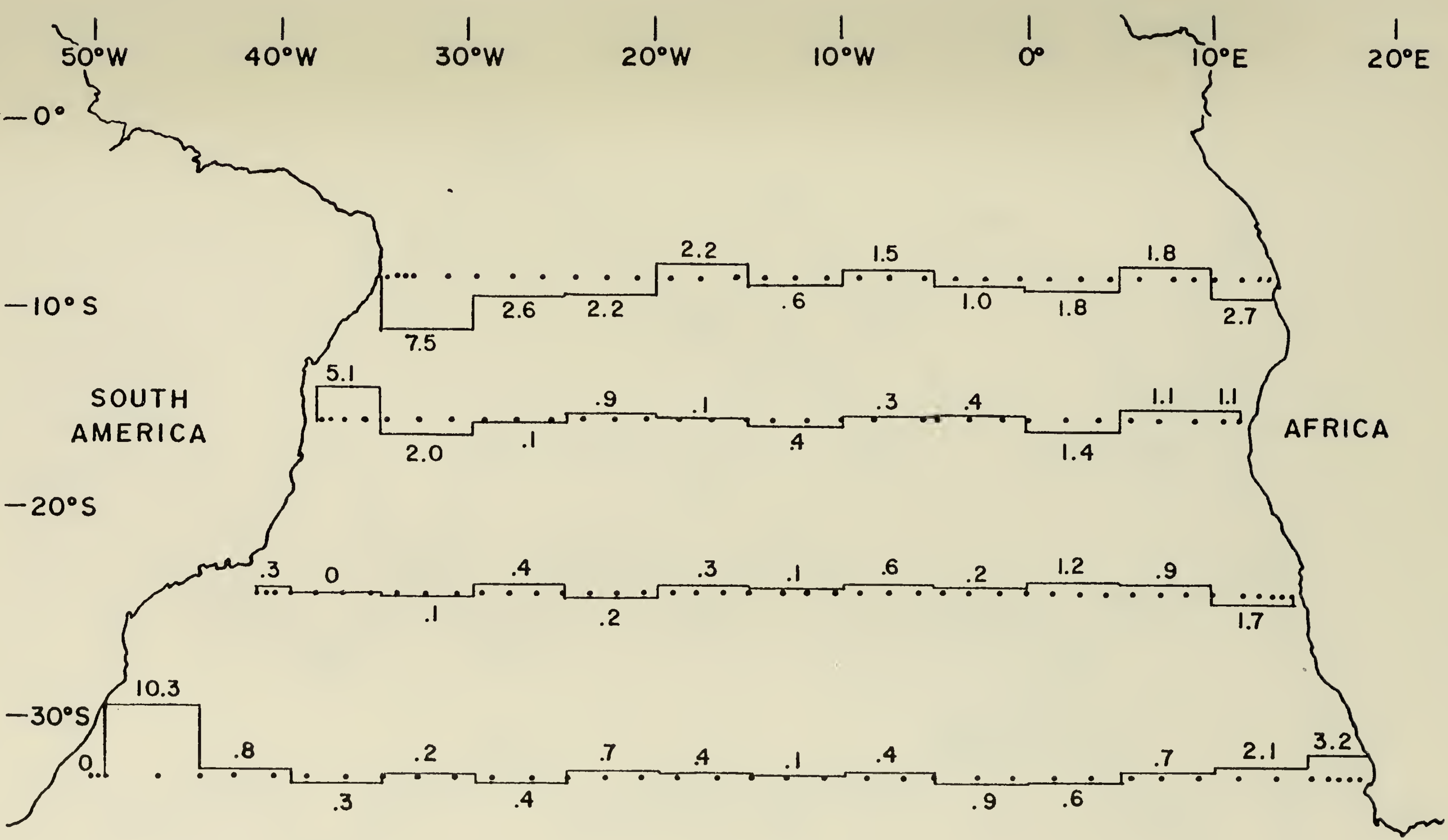


Figure 13. Integrated Mass Transports for Five Degree Increments: Intermediate Water (Fig. 18 shows circulation pattern).

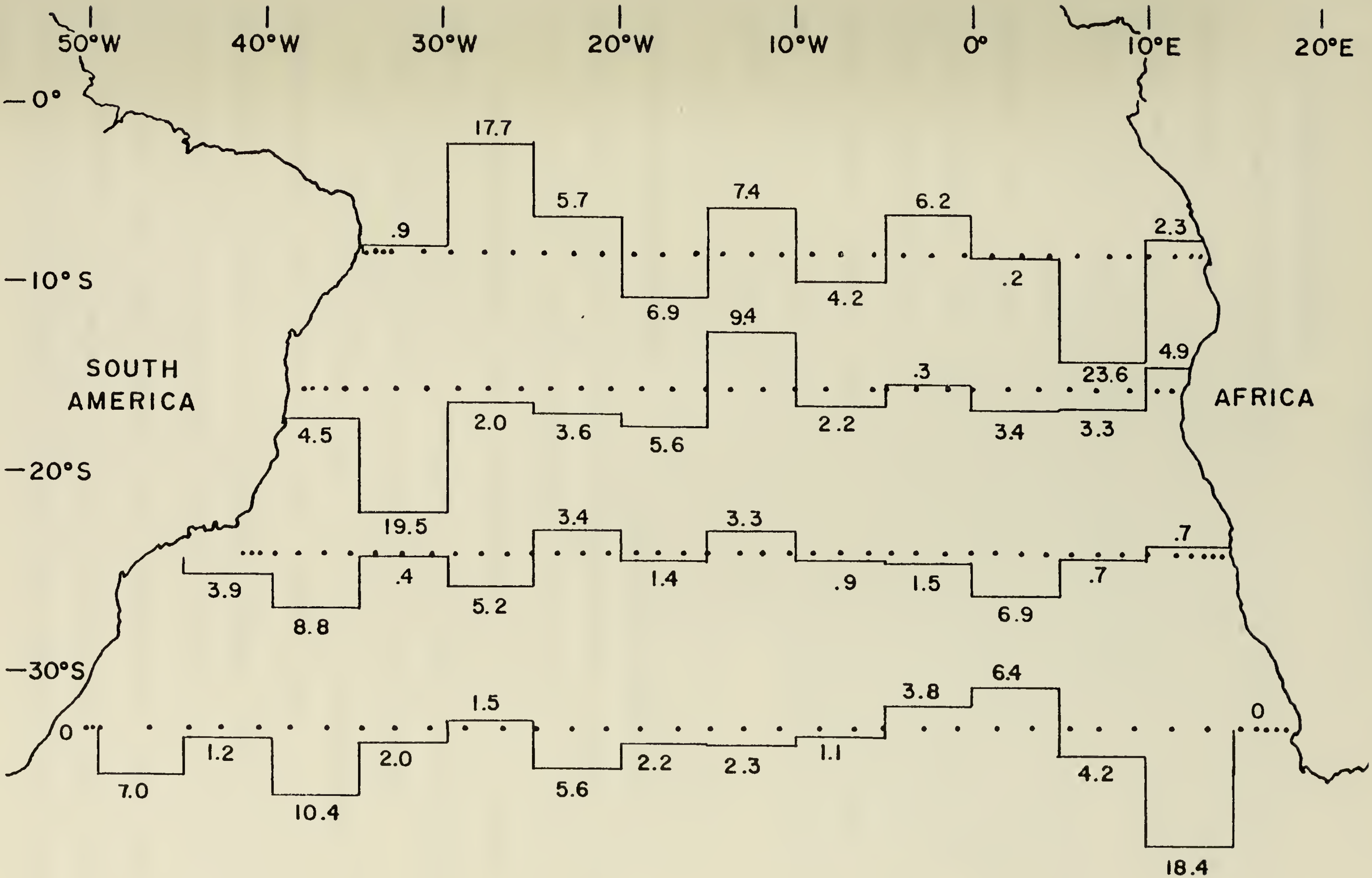


Figure 14. Integrated Mass Transports for Five Degree Increments: Deep and Bottom Water (Fig. 19 shows circulation pattern).

V. DISCUSSION OF RESULTS

A. THE LEVEL OF NO MOTION

The procedure for determining the level of no motion was taken from Sverdrup et al. (1942) as described in Section II. The resulting depths of the level of no motion obtained in this study for each section are listed in Table V and illustrated in Figures 8 through 11.

Previous evaluations of the level of no motion for the Southern Hemisphere are found in Defant (1961) and Neumann (1954, 1955). A comparison of those obtained in this study with those of Neumann shows the same general trend of deepening with increasing latitude. However, this study showed a deeper level of no motion for the region from the equator to 20°S and a shallower level of no motion for the region between 20°S and 40°S. Figure 15 illustrates the results of each study.

A comparison of the level of no motion surface with isothermal and isohaline surfaces diagrammed in the Atlantic Ocean Atlas (Fuglister, 1960) revealed that the level of no motion followed salinity surfaces between 34.55 ‰ and 34.70 ‰ and temperature surfaces between 3° and 4.1°C. The corresponding sigma-t surface averaged about 27.57 for all of the latitudes in this study. This isopyncnal surface might prove useful as a first estimate for the level of no motion at other latitudes.

Defant (1941) and Sverdrup et al. (1942) after an examination of the METEOR profiles to the south of 20°S state that the level of no motion is approximately 1100 meters at 20°S and deepens somewhat toward the south, coinciding with the boundary between Antarctic Intermediate Water and South Atlantic Deep Water. The level of no motion found in this study is also approximately 1100 meters at 20°S and coincides very closely with the boundary between the Intermediate and Deep Water masses for all latitudes studied.

TABLE V

LEVEL OF NO MOTION OBTAINED FOR
EACH LATITUDINAL CROSS SECTION

Latitude	Level of No Motion
8°S	1100 m
16°S	1300 m
24°S	1145 m
32°S	1270 m

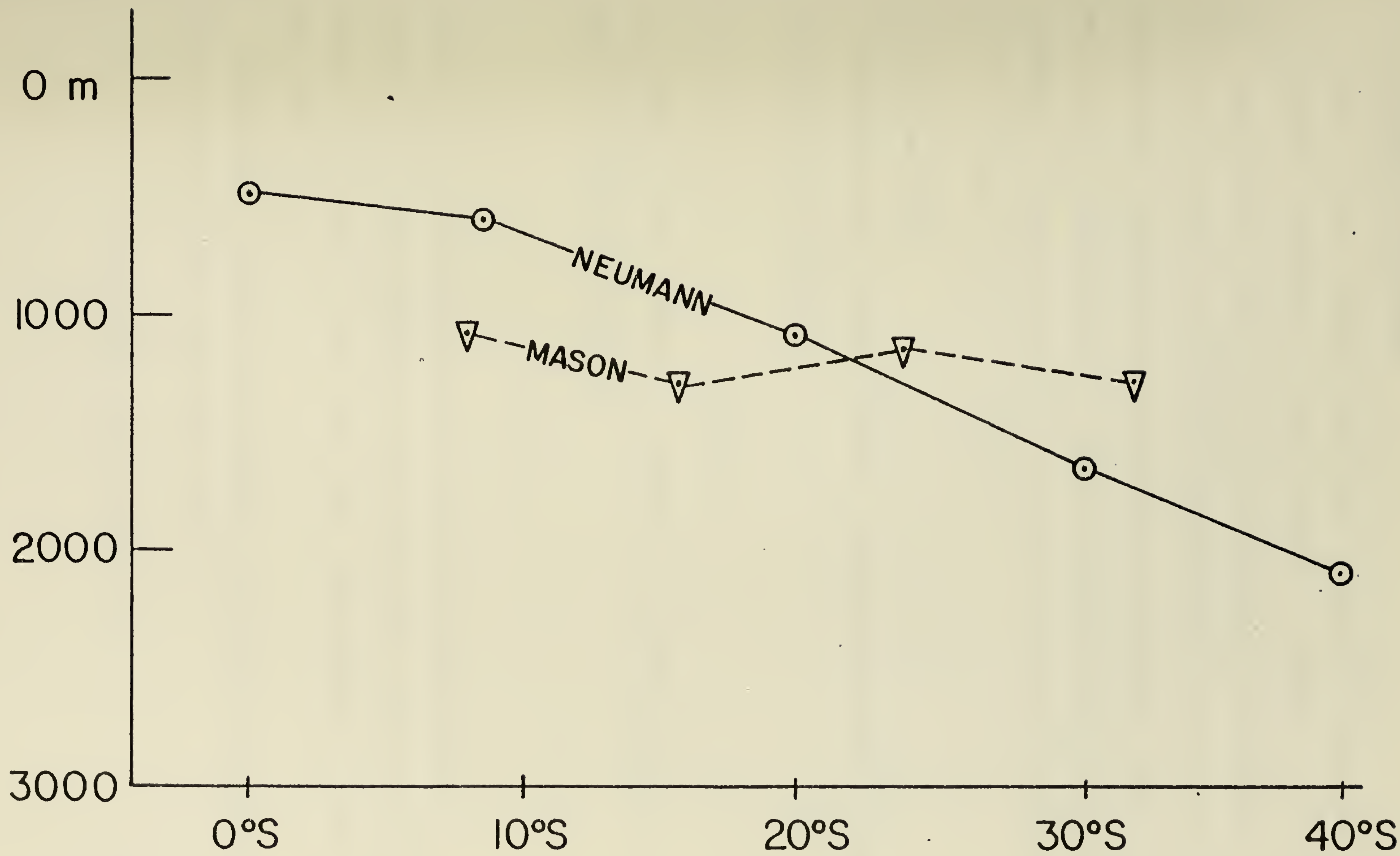


Figure 15. Comparison of Derived Level of no Motion with Previous Estimate by Neumann.

B. MASS AND SALT TRANSPORT

A mass and salt transport balance was attempted at each section as a prerequisite to estimating the heat transport. Attaining a zero net transport value for both mass and salt proved impossible; consequently, zero mass flux was chosen as the primary consideration, with zero salt flux as secondary. Excellent mass continuity and satisfactory salt continuity was attained for each section. Tables VI through IX lists the resulting transports of mass and salt for each latitude section by water mass type and the cumulative total net transport.

C. HEAT TRANSPORT

Meridional heat transport across a latitude section may be represented by the following equation:

$$\Sigma\ C_p \bar{T}\ \rho V_1\ A\ . \qquad (6)$$

By assuming the specific heat of seawater at constant pressure, C_p, to be unity, the expression reduced to

$$\Sigma\ \bar{T}\ \rho V_1\ A\ , \qquad (7)$$

where A is the cross-sectional area between the station pairs, ρV_1 is the north or south mass transport at each station pair, and $\bar{T}$ is the average absolute temperature for the station pair. The summation is across all the station pairs.

Because mass continuity was required, the net mass transports ρV_1 (north) and ρV_1 (south) must cancel, that is,

$$\Sigma \rho V_1\ (\text{north}) + \Sigma \rho V_1\ (\text{south}) = 0\ . \qquad (8)$$

TABLE VI

TRANSPORTS OF MASS AND SALT
BY WATER MASS TYPE AT 8°S

(Negative values indicate northward transport;
positive values indicate southward transport)

(all values times 10^{12})

Water Mass	Transports: Mass (gm/sec)	Transports: Salt (gm/sec)
Surface	- 6.21528	-232.87947
Central	- 1.32696	- 47.18784
Intermediate	12.78718	440.85053
Deep and Bottom	- 5.22625	-178.54060
Total for 8°S	.01869	- 17.75700

TABLE VII

TRANSPORTS OF MASS AND SALT
BY WATER MASS TYPE AT 16°S

(Negative values indicate northward transport;
positive values indicate southward transport)

(all values times 10^{12})

Water Mass	Transports Mass (gm/sec)	Transports Salt (gm/sec)
Surface	-11.24442	-413.63354
Central	-13.13231	-461.25879
Intermediate	- 5.12388	-176.45419
Deep and Bottom	29.49049	1029.91431
Total for 16°S	- .01012	- 21.43221

TABLE VIII

TRANSPORTS OF MASS AND SALT
BY WATER MASS TYPE AT 24°S

(Negative values indicate northward transport;
positive values indicate southward transport)

(all values times 10^{12})

Water Mass	Transports Mass (gm/sec)	Salt (gm/sec)
Surface	- 3.40335	-122.69826
Central	-16.98189	-597.16504
Intermediate	- 1.99157	- 68.17680
Deep and Bottom	22.35007	779.98511
Total for 24°S	- .02674	- 8.05499

TABLE IX

TRANSPORTS OF MASS AND SALT
BY WATER MASS TYPE AT 32°S

(Negative values indicate northward transport;
positive values indicate southward transport)

(all values times 10^{12})

	Transports	
Water Mass	Mass (gm/sec)	Salt (gm/sec)
Surface	- .85776	- 29.92361
Central	-25.17276	-881.97144
Intermediate	-16.78152	-576.14258
Deep and Bottom	42.82959	1494.25366
Total for 32°S	.01755	6.21603

However, a balance of the heat transport was not anticipated as a by-product of mass continuity due to the varying temperature properties of the water masses involved. The heat transports calculated by this method were taken as representative of the direction and magnitude of the actual oceanic heat transports across these latitude sections. The resulting heat transports by the various water mass types and the total heat transports across each section are listed in Table X.

Methods of computing heat transports have been proposed by Model (1950), Jung (1955), Sverdrup (1957), Bryan (1962), Sellers (1965), Emig (1967), Vander Haar and Oort (1973), and Bennett (1978). Of these, Model, Sverdrup, Emig, Bryan, and Bennett report estimates for at least one latitude in the Southern Hemisphere (see Figure 16).

Model (1950) uses an empirical and dynamical apporach to estimate transports of absolute heat through a latitude section. He estimates the heat transported by main ocean currents using volume transport and temperature information from Sverdrup et al. (1942). By determining the effects of slope currents using oceanographic station data and wind drift currents using monthly wind charts of the South Atlantic an average transport was estimated. Model obtained a figure of 150 x 10^{12} calories per second towards the north across 30°S in the South Atlantic Ocean.

Sverdrup (1957) used the heat budget equation to obtain heat transport results. He took into account heat exchange by currents, evaporation, condensation, sensible heat, and radiation excess at a given latitude through use of radiation data from Kimball (1928) and evaporation and turbulent heat flux from charts by Jacob (1957). Meridional heat transport for an ocean basin was then calculated by integrating the field of net heating with respect to latitude. A constant of integration was selected to give

TABLE X

TRANSPORTS OF HEAT BY WATER MASS
TYPE AT 8°S, 16°S, 24°S AND 32°S

Heat Transports (cal/sec) across
four latitude cross sections
(all values times 10^{12})

(Negative values indicate northward transport;
positive values indicate southward transport)

Watermass	8°S	16°S	24°S	32°S
Surface	-1853.79395	-3328.71582	- 993.78101	- 250.10114
Central	- 382.53979	-3745.13647	-4861.37500	-7184.11328
Intermediate	3553.36621	-1424.19434	- 554.42651	-4663.28906
Deep and Bottom	-1380.01392	8131.60547	6170.85547	11799.19141
Total	- 62.98145	- 366.44116	- 238.72705	- 298.31207

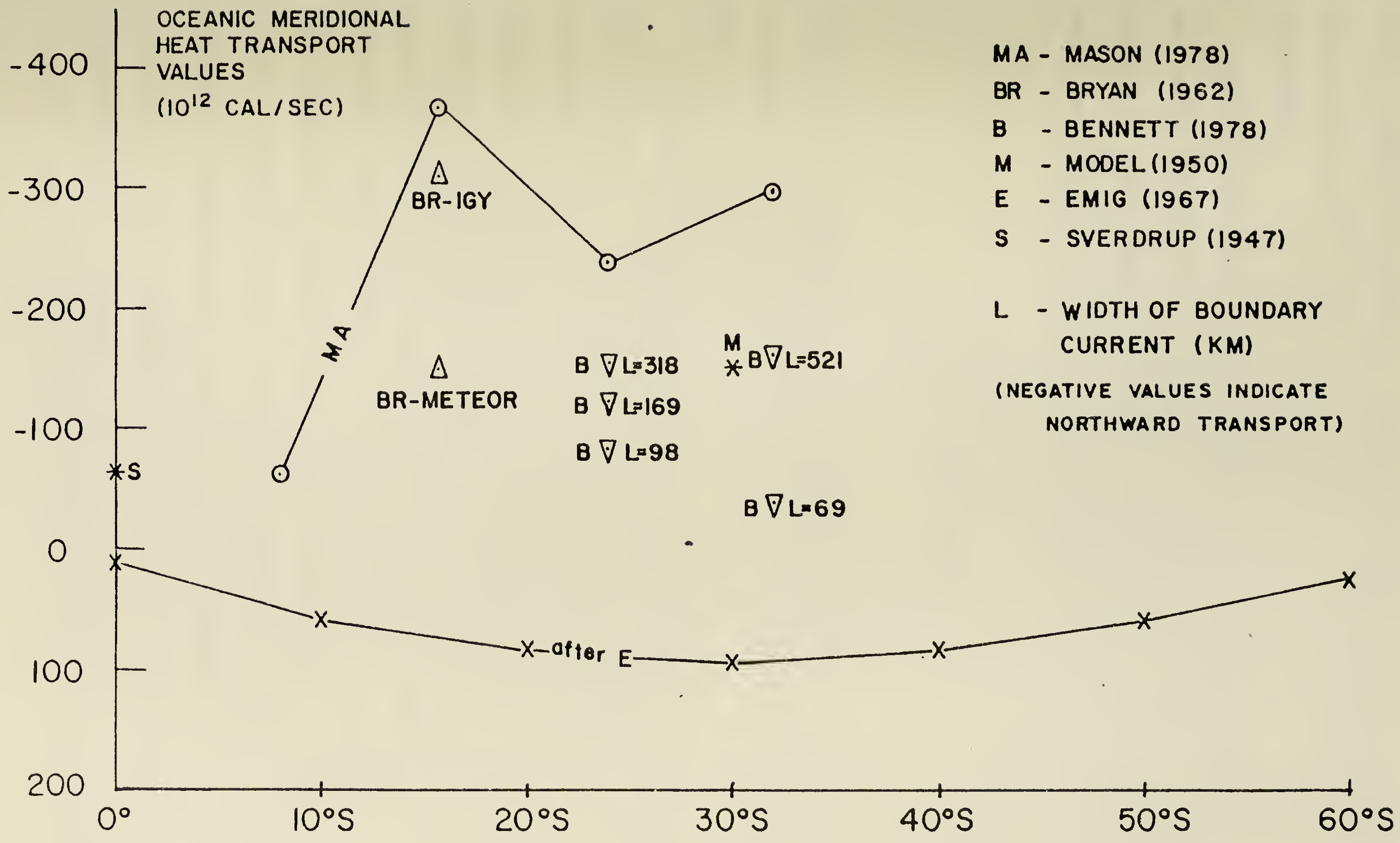


Figure 16. Comparison of Heat Transports Across Various Latitudes with Previous Works.

what he deemed as reasonable results. Sverdrup obtained an estimate of net heat transport across the equator of 67 x 10^{12} calories per second toward the north.

Bryan (1962) uses a dynamic method for combining hydrographic station data and climatological estimates of surface wind stress to calculate meridional heat transport directly. Basically the method provides an estimated value for the transport integral as given by

$$\int_{o}^{l} \int_{-H}^{o} C_p \, \theta \rho \, v dz dx \; , \qquad (9)$$

where x is the coordinate in the east-west direction, z is the vertical coordinate, v is the meridional velocity, θ is the potential temperature, and ρ is the density.

The method requires hydrographic data from which the derivative of the geostrophic volume transport is calculated. The method involves measuring the integral of the covariance of the meridional velocity and temperature over an entire vertical cross section of the ocean. Bryan divided this heat transport integral into two parts. One part can be calculated from the hydrographic data alone and is independent of any reference level of no motion. The other part of the integral is calculated from the field of surface wind stress and does require a fixed reference level. According to Bryan, Sverdrup's formula for computing the total integrated transport from the curl of the wind stress vector as used in this portion of the integral provides the most objective way to fix the reference level of no motion. This part of the integral is most important when the transport is influenced by a strong western boundary current

flowing over a shallow shelf which is compensated for by a return flow in deeper water. Bryan attempted to minimize this portion of the integral by choosing cross sections which avoided this effect.

Bryan (1962) calculated heat transports for three South Atlantic sections, all of which indicated a strong northward transfer of heat toward the equator for two 16°S and one 24°S sections. The IGY section at 16°S has a heat transfer twice that of the METEOR section at 16°S taken many years earlier. Bryan noted that circulations in the vertical meridional plane played the most important role in transports, thus confirming Jung's (1952) proposal that heat transports by such circulations in the ocean could be significantly different from those by similar atmospheric circulations at mid-latitudes.

Bennett (1978) employed Bryan's (1962) method using IGY data in the South Atlantic with differing results. Bennett begins with the same total energy transport integral as Bryan, but separates the integral into a sum of five integrals for evaluation. Bennett also employs an L parameter characterizing the width of the western boundary current. His different values of heat transport for the same latitude as illustrated in Figure 16 are due to his different guesses for the width of the boundary current. For all values of L chosen, however, Bennett's results showed strong northward (equatorward) heat transports at 24°S and 32°S.

Emig (1967) evaluated heat transports in the Atlantic Ocean by using the heat flux charts of Budyko (1962). The heat flux divergence for a latitude band was calculated as a residual by Sverdrup's heat budget method and then integrated to yield the heat transports. The boundary condition imposed was that all heat transport across 70°S be zero. The results of Emig's study are illustrated in Figure 16 and are the only estimates

which indicate a southward (poleward) heat flux across the latitude circles in the Southern Hemisphere.

The results of the present thesis study show heat transports of the same order of magnitude and same direction (northward) as in the majority of the previous cited works. The results for 16°S agree quite closely with Bryan's results using the same data and a different method. The results for 24°S and 32°S, however, are almost twice as large as those of Bryan. Results from Bryan, Bennett, and Model, however, all agree with the direction of heat transport obtained herein.

It is surprising to note the equatorward flux of heat across these Southern Hemisphere latitude sections as obtained by Model, Sverdrup, Bryan, Bennett, and Mason. The usual concept of the earth's heat budget would seem to suggest just the opposite result. Ordinarily, the heat balance is described as a poleward flux of heat in both atmosphere and ocean to offset the sun's excess radiation in the tropical regions and deficit in the polar regions. Indeed, this must be the case averaged worldwide, since, over time periods of a century or so, the tropics are not getting warmer nor the poles colder. However, the results of this study and the consensus of previous works indicates that for the South Atlantic at least the oceanic heat flux is in a direction opposite to that expected within the entire fluid envelope.

Bryan (1962) and Bennett (1978) examined several reasons for the unexpected results. Bryan (1962) implied that many of the earliest estimates of heat flux concentrated on transports by horizontal currents and ignored circulations in the vertical plane associated with the thermohaline circulations as originally proposed by Jung (1952). Bryan's results show that while vertical circulations are weak in terms of volume transport,

they dominate the heat transport. It is, therefore, the warmer surface currents with a net northward flux which dominate the net southward flux of cooler deeper water in terms of absolute heat content. However, Bryan does state that the spacing of hydrographic stations is not dense enough to define the role of transient meanders which may have a significant effect on heat transport. For example, Newton (1961) reports that a single Gulf Stream meander can lead to a meridional heat transport of 1 to 2 x 10^{14} calories per second, a value larger than many of the net heat transports for an entire latitude section. Meanders and eddies in the South Atlantic are not defined sufficiently so as to estimate their effect on the METEOR or IGY data.

Bennett (1978), in agreement with Bryan states that conventionally spaced stations do not resolve the mid-ocean eddy field; however, he does attempt some estimate of eddy flux contributions to heat flux. He concludes that even though the eddy contributions are not negligible, they do not account for the unexpected northward heat flow. It is the large scale flow which is responsible for the northward heat flux, and, although eddies introduce variability into the heat flux estimates, they do not dominate the results.

It appears that this northward oceanic heat transport must be compensated by either the atmospheric heat transport of the Southern Hemisphere, or by oceanic transports southward in other Southern Hemispheric oceans.

Another possibility is that the northward oceanic heat transport is a seasonal effect which may be compensated by a reversal in another part of the year. It is to be noted that three of the cross sections were associated with the Southern Hemispheric autumn season and only the 24°S cross section was from the Southern Hemisphere spring season. It is

possible that the oceanic heat transports may be equatorward during these transition seasons and poleward at other times.

D. GENERAL CIRCULATIONS BASED ON MASS TRANSPORT

The general circulation pattern was drawn according to the procedures described in Section IV-F. The resulting eddy circulations are consistent with the pattern of mass transport vectors illustrated in Figures 17 through 19.

Eddy circulations in the North Atlantic have been studied extensively by Iselin (1936, 1940), Fuglister (1947, 1963, 1971), Iselin and Fuglister (1948), Fuglister and Worthington (1951), Barrett (1963), Richardson (1976), and Parker (1971). The eddy fluctuations discussed in the literature are usually associated with the Gulf Stream, but eddies of similar characteristics occur in the other oceans. The typical eddy is a low frequency mesoscale phenomenon with a diameter between 100 and 200 kilometers. Robinson (1976) described the mid-ocean eddy as a feature orders of magnitude more energetic than the main flow. These eddies exist as cyclonic and anti-cyclonic rings extending from the surface to the bottom as measured in the MODE-I experiment.

Only eddies the diameter of one station pair or greater are detectable by the method used in this thesis. Most of the eddies persist with depth through the surface, central and intermediate water, and then reverse their direction of rotation in the deeper regions. This reversal of circulation with depth has been reported in the Northern Hemisphere by McCartney, Worthington, and Schmitz (1978).

Figures 17 through 19 indicate the derived circulation system, depicting a hypothetical gyre pattern for the South Atlantic which best explains some of the observed features. All mass units are in terms of 10^{12} gm/sec.

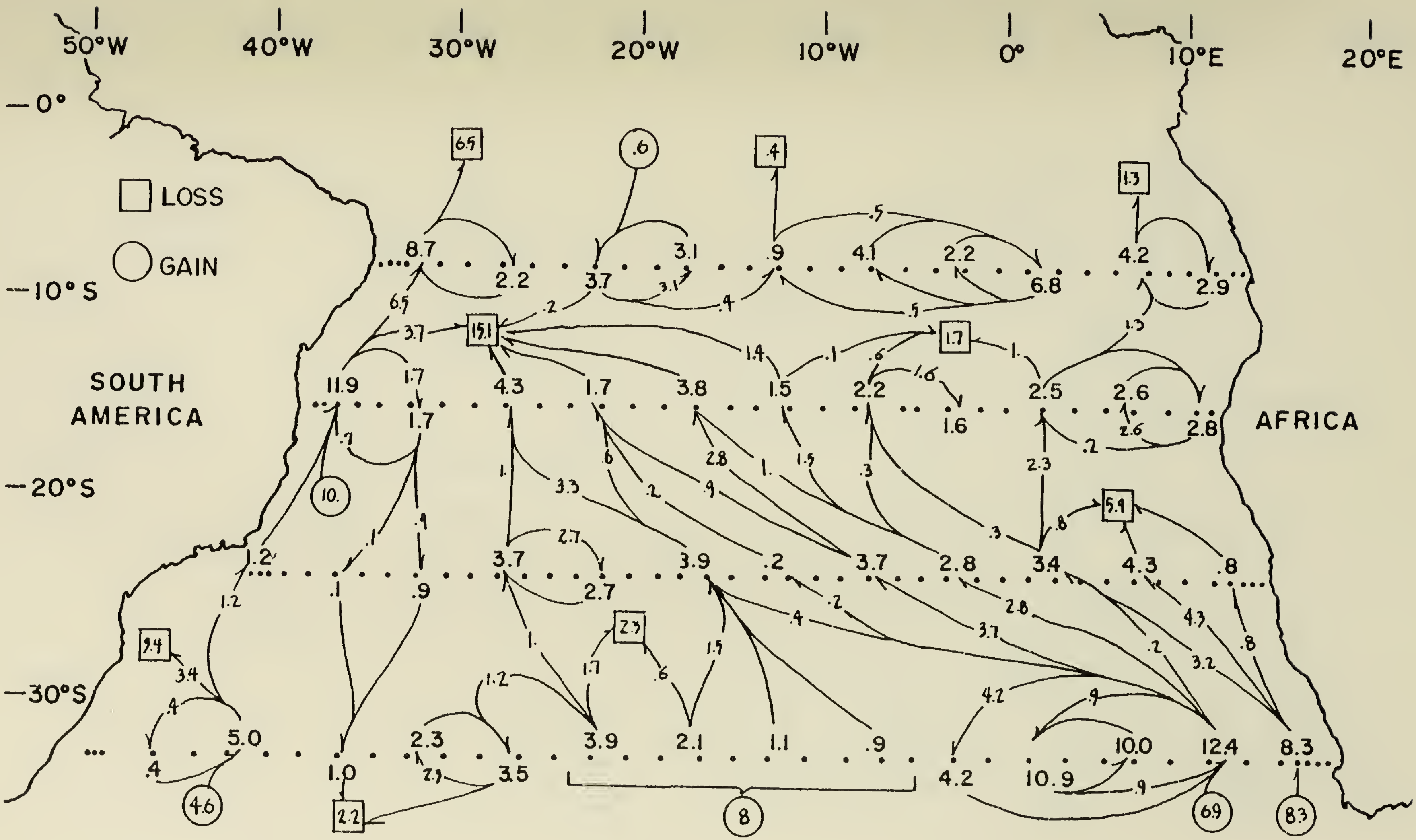


Figure 17. Circulation Patterns Based on Mass Transport Vectors: Upper Water.

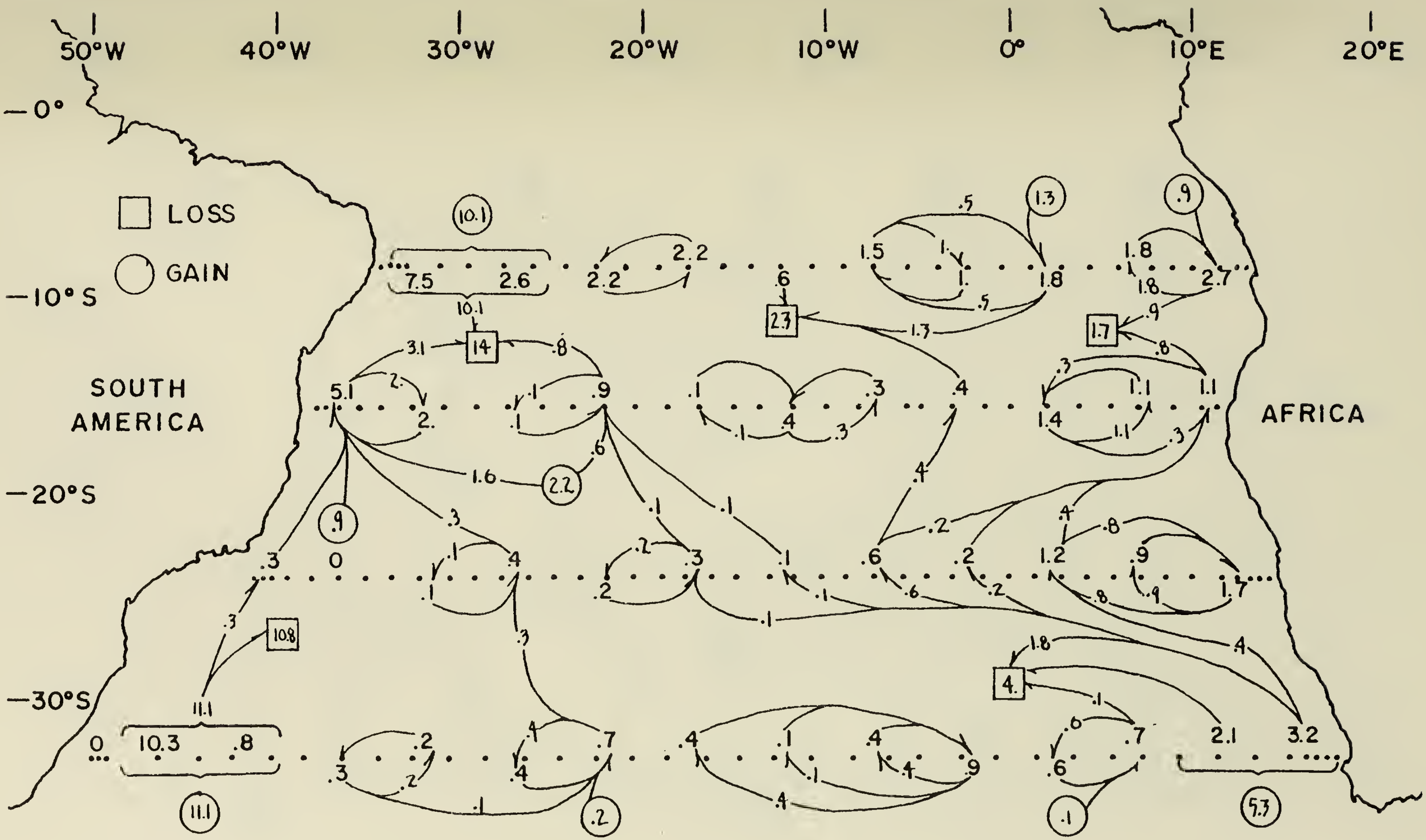


Figure 18. Circulation Patterns Based on Mass Transport Vectors: Intermediate Water.

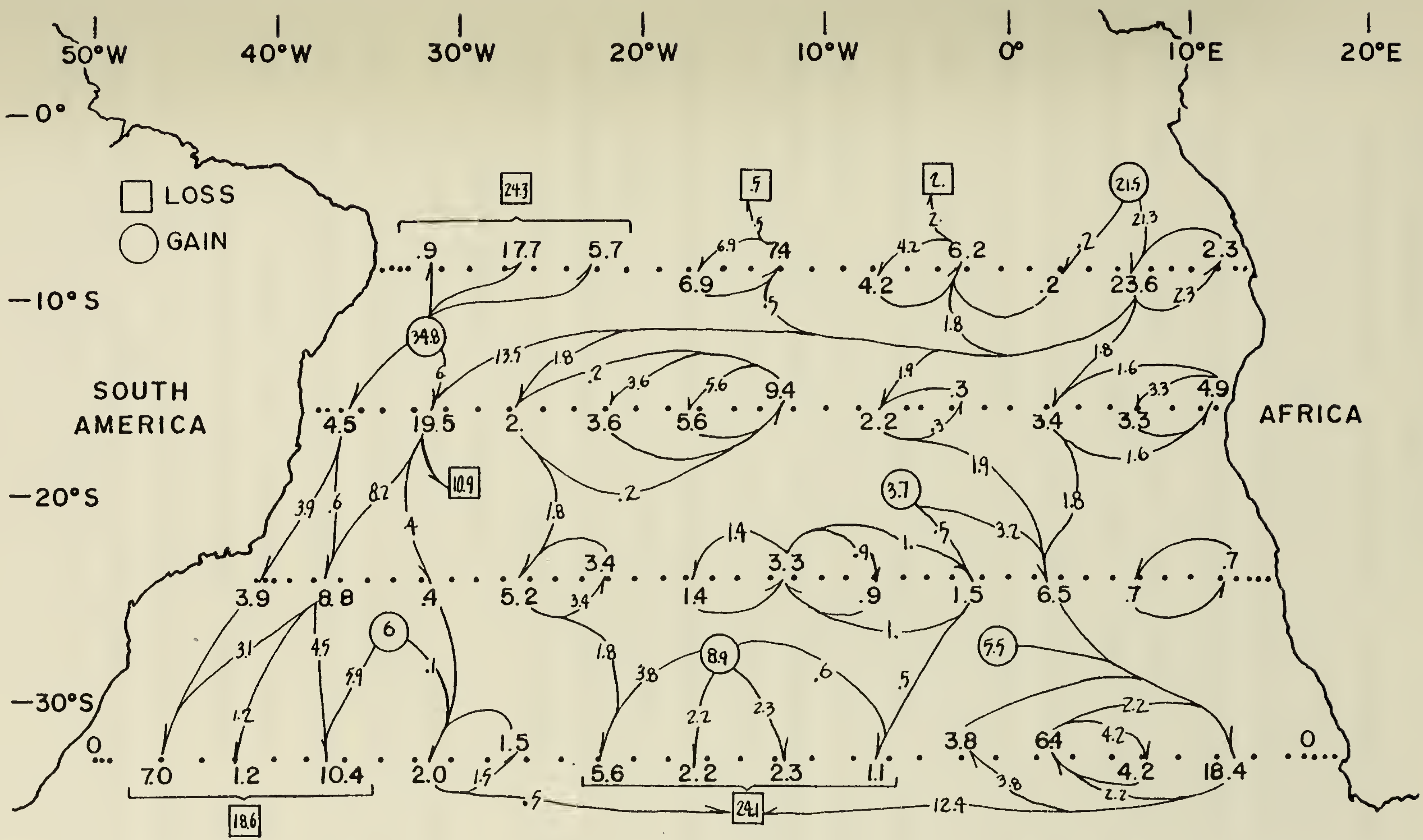


Figure 19. Circulation Patterns Based on Mass Transport Vectors: Deep and Bottom Water.

1. The Circulation in the Upper Water

The Benguela Current, powered mainly by the prevailing southeast trades, is a slow-moving current flowing north along the western coast of Africa. It is most constant in speed and direction between Cape Agulhas and 25°S with well-defined nearly stationary boundaries. North of this region there is a confused coastal part and a steady oceanic part of the current (Boisvert, 1967). Figure 17 shows the narrow flow at 30°S broadening and becoming more zonal as it progresses northward. A net northward flow of 15.6 units is comparable with 16 units derived by Sverdrup et al. (1942) for the same current. Some convergence and sinking, 2.3 units, is seen in the area of the Subtropical Convergence Zone. The Atlantic South Equatorial Current is clearly seen as the more zonal westward flow between 16°S and 24°S. North of 15°S a more confused gyre pattern is pictured with large convergence, 16.8 units, between 15°S and 8°S. The cyclonic gyre centered at 16°S, 17°E matches geostrophic calculations by Moroshkin et al. (1967). The less distinct westward flow of the Atlantic South Equatorial Current between 8°S and 20°S matches the flow described by Mazeika (1968) who detected both surface and subsurface geostrophic currents flowing eastward in this region.

Notably absent in this depiction is the expected strong Brazil Current which flows southwest parallel to the Brazil coast. Sverdrup et al. (1942) estimated 10 units of transport in a southerly direction across 30°S for the Brazil Current as compared to only one unit in Figure 17. Indeed, further north the Brazil Current even appears reversed. In view of the fact that the surface currents for the area compare favorably with Sverdrup's estimates, and yet the volume transports do not, the disagreement may stem from the great variability in the Brazil Current.

The Brazil Current is the southward extension of the Atlantic South Equatorial Current which divides at approximately 10°S. The seasonal boundaries and speeds are more variable than most other major currents and its variation in speed and direction is greater than the Atlantic South Equatorial Current from which it originates. Numerous counter-currents exist from seasonal increases in the river discharge of the Rio de la Plata, a coastal extension of the Falkland Current, and strong tidal rotations. The surface currents particularly exhibit both clockwise and counterclockwise rotations from tidal influences with reversals and diurnal inequalities adding to the confusion (Boisvert, 1967).

The variability of the Brazil Current could affect this study in several ways. If the Brazil Current were exceptionally weak at the time of measurement the lack of influence in the surface and central waters would be explained. This study of circulation patterns by mass transport vectors indicates that the strength of the southward flowing western ocean boundary current is concentrated in the Deep and Bottom Water (Figure 19).

Secondly, if the Brazil Current were very narrow in the upper reaches of the water column, its contribution to the mass transport would be small due to the reduced cross sectional area through which it flows. The depiction of circulation through the vertical cross sections at each latitude are to be found in Appendix III; it is apparent that the southward flowing currents in the region of the Brazil Current are of high velocity but small in areal extent.

Thirdly, a local anomaly in the level of no motion would cause an error in the absolute velocities which would reduce the effect of the Brazil Current. It is doubtful that such an error would extend across the entire cross section since the remainder of the circulation picture closely matches observations and previous estimates of volume transports.

Finally, the more northward extension of the Falkland Current and more southward extension of the Guiana Current during the local autumn (March-May) season, when observations for the 8°S, 16°S, and 32°S cross sections were conducted, may explain the reduced value for southward transport.

Sverdrup's values for transport are in terms of volume transport converted to cm^3/sec, whereas this study used mass transport, with gm/sec units. A comparison by Cummings (1977) showed less than a 2.7% error in equating these two transports.

2. The Circulation in the Intermediate Water

Quantitative volume transport information below the surface of the South Atlantic is scarce. Sverdrup *et al*. (1942) estimates a net northward transport across 30°S of 9 units for the intermediate level compared with the 16.7 units obtained in this study across 32°S. For the remaining latitudes general trends are apparent. Some deeper elements of the Benguela Current and Atlantic South Equatorial Current systems are evident in the western and middle portion of Figure 18 at these depths. The transports are generally weaker in this layer than for any other and circulation patterns are not well defined.

3. The Circulation in the Deep and Bottom Water

The primarily southward transport of deep water normally observed in current studies is verified in Figure 19. There is a distinct southward mass transport along the westward boundary and a total net southward transport across 16°S, 24°S, and 32°S. Sverdrup's (1942) estimate of a southward transport of 18 units by the deep water is less than one half of the estimate of 42 units obtained here. The northward flowing Antarctic Bottom Water was not detected by the Nansen casts and is not seen in Figure 19. Consequently, the computer attributed its contribution

to the more southerly flow of the Deep Water by default. The northward contribution from Antarctic Bottom Water is only approximately 3 units at 30°S according to Sverdrup et al (1942). Therefore, the abnormally high estimate of mass transport for Deep and Bottom Water combined is not explained by lack of detecting geostrophic currents in the Bottom Water. It does represent an approximation for geostrophic transport based on accurate station data.

VI. CONCLUSIONS

This study used the classical dynamic approach for calculating geostrophic currents to determine mass, salt, and heat transports using oceanographic station data. The results showed an equatorward heat flux in the subtropical South Atlantic at all the latitudes studied. The direction of the flow agreed with the majority of previous estimates by Sverdrup et al. (1942), Bryan (1962), Bennett (1978), and Model (1950). The magnitude, however, was in most cases greater than previous works, with rough agreement with Bryan (1962) at 16°S, and values almost twice as large as the average for Bennett's results for 24°S and 32°S. It is concluded that this unexpected equatorward heat transport is due to warmer surface currents with a net northward flux carrying more energy northward than the deeper cooler waters carry southward.

A level of no motion was experimentally determined in the subtropical South Atlantic which had a trend of deepening with increasing latitude similar to previous results, but did not deepen as sharply with increasing latitude as that of Neumann (1966). The level of no motion was closely related to the sigma-t surface of $\sigma_t = 27.57$ and was most often located near the bottom-most boundary of the Antarctic Intermediate Water mass.

The method employed also provided a useful picture of the absolute geostrophic velocities to be expected in the region. The derived circulation based on mass transport figures corresponds closely with observed circulations, and for the first time demonstrate a quasi-synoptic view of the major transport mechanisms in the South Atlantic.

MASS TRANSPORT AT 8 DEGREES SOUTH
UNITS ARE (GRAMS/SEC) X E12

STATION NUMBERS	SURFACE	S.ATLANTIC CENTRAL	ANTARCTIC INTERMED	DEEP AND BOTTOM	STATION TOTAL
120/ 119	-1.88230	-0.70249	8.15118	0.0	5.56639
119/ 118	2.82971	4.56023	2.79065	25.91177	36.09235
118/ 117	1.84928	-3.33438	-0.97540	-21.19501	-23.65550
117/ 116	-3.41144	-0.69177	-1.06866	-3.09819	-8.27005
116/ 115	-3.55903	-4.49622	-1.67132	-2.48235	-12.20892
115/ 114	-1.47938	0.00939	-1.59341	0.53545	-2.52795
114/ 113	1.44400	1.82823	3.97451	-6.35583	0.89090
113/ 112	-0.59728	0.94075	0.17224	-11.88714	-11.37143
112/ 111	-2.02896	-1.86410	-0.67864	10.34165	5.76994
111/ 110	0.81250	4.88095	2.27380	-7.75407	0.21319
110/ 109	0.49441	1.38104	0.58711	-8.28137	-5.81880
109/ 108	-0.26294	-2.89458	-1.48703	13.60081	8.95626
108/ 107	-2.05246	-0.53805	-0.73290	1.07748	-2.24592
107/ 106	1.83268	0.82817	0.02420	-7.85974	-5.17469
106/ 105	0.53925	1.50807	2.84651	6.35727	11.25109
105/ 104	-2.73581	-3.27095	-2.15284	-5.09078	-13.25038
104/ 103	0.65420	2.48349	1.81778	-8.72872	-3.77325
103/ 102	-0.64618	-1.00963	-2.53068	16.22862	12.04212
102/ 101	-0.58449	-1.83036	-0.85033	-11.95189	-15.21706
101/ 100	-0.11061	-1.12574	0.37195	17.17662	16.31223
100/ 99	-0.52184	2.46878	2.13072	-25.07199	-20.99434
99/ 98	-0.39020	-2.55881	-1.52495	1.82761	-2.64635
98/ 97	1.42171	4.08294	3.33450	-7.16035	1.67879
97/ 96	-0.24708	1.09381	-1.17776	23.75642	23.42538
96/ 95	0.84085	-0.32618	-0.29237	-16.39400	-16.17169
95/ 94	-1.01364	3.53671	1.12494	-6.33533	-2.68733
94/ 86	0.52146	0.09891	-0.56948	6.51923	6.57013
86/ 92	-1.00791	-6.55735	-2.19844	-4.48582	-14.24951
92/ 87	0.34976	-0.04979	-0.05979	27.89127	28.13144
87/ 89	0.24557	-0.23697	0.04855	-2.31965	-2.26250
89/ 90	2.63234	0.35993	2.70271	0.0	5.69498
90/ 91	-0.15148	0.09899	0.0	0.0	-0.05249
TOTALS	-6.21528	-1.32696	12.78718	-5.22625	0.01869

SALT TRANSPORT AT 8 DEGREES SOUTH
UNITS ARE (GRAMS/SEC) X E12

STATION NUMBERS	SURFACE	S.ATLANTIC CENTRAL	ANTARCTIC INTERMED	DEEP AND BOTTOM	STATION TOTAL
120/ 119	-68.71750	-25.05519	280.78760	0.0	187.01491
119/ 118	104.03464	160.06461	96.26347	905.57593	1265.93848
118/ 117	67.52283	-116.96352	-33.66789	-739.23242	-822.34082
117/ 116	-123.55237	-24.46971	-36.88582	-108.00774	-292.91553
116/ 115	-129.77869	-157.30606	-57.69824	-87.20662	-431.98950
115/ 114	-54.04836	0.26382	-55.00020	17.98528	-90.79945
114/ 113	52.73405	63.86223	137.22633	-220.22208	33.60054
113/ 112	-21.81482	32.87830	5.95010	-413.80762	-396.79395
112/ 111	-74.22707	-65.25465	-23.43983	358.62915	195.70760
111/ 110	29.48232	170.35423	78.48370	-268.24194	10.07813
110/ 109	17.90802	47.89774	20.26642	-288.90332	-202.83115
109/ 108	-9.48959	-100.91823	-51.32576	474.77563	313.04199
108/ 107	-74.28694	-19.00336	-25.30638	37.61560	-80.98108
107/ 106	66.35736	29.37032	0.82919	-274.48291	-177.92606
106/ 105	19.52872	52.42680	98.28232	222.10899	392.34668
105/ 104	-99.40471	-114.71849	-74.32747	-177.85849	-466.30884
104/ 103	23.72679	87.02287	62.74625	-304.72168	-131.22577
103/ 102	-23.41179	-35.36215	-87.36122	566.54224	420.40698
102/ 101	-21.15569	-63.78964	-29.35797	-417.26953	-531.57275
101/ 100	-3.95682	-39.42845	12.84060	599.66528	569.12061
100/ 99	-18.83945	86.28253	73.59808	-875.31323	-734.27197
99/ 98	-14.01861	-89.42661	-52.67293	63.84589	-92.27225
98/ 97	51.01614	142.59671	115.16435	-249.89467	58.88243
97/ 96	-8.97977	38.36366	-40.67592	829.16504	817.87280
96/ 95	30.35875	-11.27655	-10.10126	-572.14478	-563.16382
95/ 94	-36.50237	124.09825	38.85493	-221.05609	-94.60527
94/ 86	18.66048	3.81034	-19.67529	227.54459	230.34010
86/ 92	-35.36011	-230.71710	-75.95375	-156.62373	-498.65430
92/ 87	11.95089	-1.52736	-2.07183	974.03687	982.38843
87/ 89	8.21436	-8.38084	1.67772	-81.08890	-79.57765
89/ 90	88.28738	13.57398	93.44139	0.0	195.30275
90/ 91	-5.12048	3.54334	0.0	0.0	-1.57713
TOTALS	-232.87947	-47.18784	440.85083	-178.54060	-17.75691

HEAT TRANSPORT AT 8 DEGREES SOUTH
UNITS ARE (CAL/SEC) X E12

STATION NUMBERS	SURFACE	S.ATLANTIC CENTRAL	ANTARCTIC INTERMED	DEEP AND BOTTOM	STATION TOTAL
120/ 119	-554.22046	-203.39177	2265.06470	0.0	1507.45264
119/ 118	844.30664	1298.46777	777.62256	7179.37109	10099.76563
118/ 117	555.00122	-949.93408	-272.17896	-5837.00391	-6504.11328
117/ 116	-1018.76831	-198.86005	-297.42798	-851.90210	-2366.95825
116/ 115	-1063.41577	-1274.24536	-465.62402	-692.19604	-3495.48120
115/ 114	-442.72046	2.16671	-443.27441	139.36641	-744.46167
114/ 113	431.33472	517.40601	1106.56812	-1735.79761	319.51123
113/ 112	-179.76622	266.23584	48.11691	-3265.04541	-3130.45874
112/ 111	-603.49512	-528.57520	-189.48653	2825.59961	1504.04297
111/ 110	238.83308	1380.18774	633.11108	-2112.49634	139.63550
110/ 109	148.06967	388.08813	163.62822	-2281.98755	-1582.20166
109/ 108	-77.41840	-817.38086	-413.90845	3752.44922	2443.74170
108/ 107	-611.14551	-153.88748	-204.15976	298.39551	-670.79712
107/ 106	545.24170	237.91399	6.94573	-2170.18604	-1380.08496
106/ 105	159.65637	424.64038	792.57275	1757.26978	3134.13916
105/ 104	-813.94971	-929.42944	-599.55542	-1407.13818	-3750.07275
104/ 103	194.02765	705.03784	505.60620	-2411.44043	-1006.76880
103/ 102	-191.56374	-286.25586	-703.62671	4482.64063	3301.19434
102/ 101	-173.22946	-516.70898	-237.15720	-3300.88965	-4227.98438
101/ 100	-32.21147	-319.43799	103.26537	4738.89453	4490.50781
100/ 99	-155.23708	699.14722	593.12036	-6918.82031	-5781.78906
99/ 98	-114.58414	-724.69629	-424.56665	507.96948	-755.87744
98/ 97	420.27710	1155.53955	928.44629	-1976.93237	527.33057
97/ 96	-74.47563	311.09155	-327.71948	6552.39453	6461.28906
96/ 95	249.09895	-91.26857	-81.55988	-4520.48438	-4444.21094
95/ 94	-300.09424	1006.03516	313.32642	-1746.83740	-727.57007
94/ 86	153.24223	31.07802	-158.72154	1796.69336	1822.29199
86/ 92	-296.14966	-1867.98901	-611.95752	-1236.06055	-4012.15674
92/ 87	102.68407	-12.63056	-16.48810	7695.02344	7768.58594
87/ 89	72.18622	-67.62253	13.35122	-641.33496	-623.41992
89/ 90	780.03223	107.95622	750.07471	0.0	1638.06299
90/ 91	-45.34482	28.77562	0.0	0.0	-16.56920
TOTALS	-1853.79395	-382.53979	3553.36621	-1380.01392	-62.98145

MASS TRANSPORT AT 16 DEGREES SOUTH
UNITS ARE (GRAMS/SEC) X E12

STATION NUMBERS	SURFACE	S.ATLANTIC CENTRAL	ANTARCTIC INTERMED	DEEP AND BOTTOM	STATION TOTAL
121/ 122	-0.44618	-0.16719	3.02564	0.0	2.41227
122/ 123	-0.20666	-3.42388	-3.63605	-0.20090	-7.46749
123/ 124	-1.90892	-6.18782	-6.59615	4.71605	-9.97684
124/ 125	-0.42395	0.80962	2.18108	19.98500	22.55174
125/ 126	1.97642	-0.32677	0.78863	11.76451	14.20279
126/ 127	-0.94237	1.04408	1.66141	-12.34019	-10.57707
127/ 128	-1.77582	-0.46897	-0.52176	2.71264	-0.05392
128/ 129	-1.93481	-0.42705	0.04275	-10.12932	-12.44842
129/ 130	0.45499	-0.25759	0.10523	9.42737	9.73000
130/ 131	-0.50953	-0.07270	1.65020	-4.89608	-3.82812
131/ 132	-0.13661	0.20214	-1.41586	6.79549	5.44517
132/ 133	-0.74069	-0.45691	-1.12895	1.68146	-0.64508
133/ 134	-0.14766	-0.44572	0.03330	-0.81474	-1.37482
134/ 135	-1.94671	-1.02249	-0.04440	4.59577	1.58217
135/ 136	-0.06943	-0.15913	-0.09987	1.79808	1.46965
136/ 137	-0.96526	-0.92690	0.36283	-4.60888	-6.13822
137/ 138	-0.15500	0.01390	-0.14369	-5.78289	-6.06767
138/ 139	0.07429	0.45317	0.10871	0.98452	1.62069
139/ 140	-0.24979	-0.35281	-0.04260	3.28965	2.64445
140/ 141	-0.03912	0.98867	1.52341	-7.20818	-4.73523
141/ 142	-0.84147	-1.68524	-1.81264	6.10735	1.76800
142/ 143	0.38722	1.77959	0.43587	-5.15113	-2.54845
143/ 144	-0.15665	-0.75428	-1.32975	4.64763	2.40694
144/ 145	-0.15804	0.47064	0.52982	0.34811	1.19054
145/ 146	-0.45370	-1.53363	-0.47080	6.44820	3.99007
146/ 147	-0.09031	2.80577	3.34895	-8.29230	-2.22789
147/ 148	-0.05317	-3.10486	-1.48983	5.32863	0.68077
148/ 149	-0.19305	-0.26648	-0.65251	0.95544	-0.15659
149/ 150	0.23547	-0.50148	0.20905	1.30245	1.24549
150/ 151	-0.80576	-1.01534	-0.63615	0.95885	-1.49840
151/ 152	0.81434	1.29230	-1.44119	-4.92852	-4.26307
152/ 153	0.16347	0.56496	0.33131	0.0	1.05973
TOTALS	-11.24442	-13.13231	-5.12388	29.49049	-0.01010

SALT TRANSPORT AT 16 DEGREES SOUTH
UNITS ARE (GRAMS/SEC) X E12

STATION NUMBERS	SURFACE	S.ATLANTIC CENTRAL	ANTARCTIC INTERMED	DEEP AND BOTTOM	STATION TOTAL
121/ 122	-16.49490	-5.94943	104.16962	0.0	81.72530
122/ 123	-7.48606	-119.71475	-125.12486	-6.96609	-259.29175
123/ 124	-70.40956	-216.94827	-227.07097	164.91350	-349.51489
124/ 125	-15.70598	28.26271	75.15009	698.05957	785.76636
125/ 126	73.45686	-11.64832	27.20386	410.63843	499.65063
126/ 127	-35.09483	36.76996	57.24609	-430.64014	-371.71875
127/ 128	-65.65259	-16.39355	-17.97206	94.49612	-5.52208
128/ 129	-71.55952	-15.08612	1.49105	-353.10840	-438.26294
129/ 130	16.83540	-9.05764	3.62513	328.61670	340.01953
130/ 131	-18.67319	-2.58885	56.99352	-170.89288	-135.16139
131/ 132	-4.94563	6.98554	-48.92795	236.82227	189.93423
132/ 133	-27.31114	-15.94776	-38.92934	58.68941	-23.49883
133/ 134	-5.43955	-15.65782	1.14524	-28.41873	-48.37085
134/ 135	-71.33163	-36.26695	-1.54603	160.42795	51.28334
135/ 136	-2.57689	-5.49270	-3.43413	62.76604	51.26230
136/ 137	-35.23466	-32.60904	12.51715	-160.89973	-216.22629
137/ 138	-5.67201	0.33038	-4.94928	-201.87007	-212.16098
138/ 139	2.71275	15.98549	3.73509	34.37029	56.80360
139/ 140	-9.12178	-12.51931	-1.46377	114.80618	91.70134
140/ 141	-1.42113	34.33546	52.59285	-251.55238	-166.04521
141/ 142	-30.63278	-58.91220	-62.58548	213.16821	61.03775
142/ 143	14.05995	62.26810	15.03249	-179.76991	-88.40938
143/ 144	-5.69466	-26.25685	-45.92502	162.20531	84.32878
144/ 145	-5.74082	16.34717	18.30847	12.13211	41.04691
145/ 146	-16.46175	-53.75485	-16.26503	225.03993	138.55830
146/ 147	-3.27293	98.12582	115.67918	-289.47412	-78.94205
147/ 148	-1.91865	-108.76060	-51.47264	185.99052	23.83864
148/ 149	-6.95983	-9.33417	-22.56088	33.33844	-5.51643
149/ 150	8.37776	-17.56131	7.23597	45.48213	43.53455
150/ 151	-28.43855	-35.61534	-21.98442	33.48189	-52.55643
151/ 152	28.49274	45.39386	-49.80379	-171.88126	-147.79845
152/ 153	5.67775	19.98553	11.43299	0.0	37.09627
TOTALS	-413.63354	-461.25879	-176.45419	1029.91431	-21.43213

HEAT TRANSPORT AT 16 DEGREES SOUTH
UNITS ARE (CAL/SEC) X E12

STATION NUMBERS	SURFACE	S.ATLANTIC CENTRAL	ANTARCTIC INTERMED	DEEP AND BOTTOM	STATION TOTAL
121/ 122	-133.06561	-48.30283	838.51172	0.0	657.14307
122/ 123	-60.19104	-972.33008	-1010.51782	-53.65146	-2096.69019
123/ 124	-565.82471	-1761.05420	-1830.21899	1305.22192	-2851.87573
124/ 125	-126.15031	229.58040	605.68164	5514.97266	6224.08203
125/ 126	593.11646	-94.28375	218.57265	3242.70679	3960.11182
126/ 127	-284.04517	297.95532	461.56152	-3401.32446	-2925.85278
127/ 128	-528.43408	-133.06711	-144.99217	745.10156	-61.39136
128/ 129	-574.96533	-122.37030	11.63897	-2787.99976	-3473.69604
129/ 130	135.36224	-73.50360	29.18329	2595.45410	2686.49585
130/ 131	-150.52507	-20.97781	457.19873	-1351.06372	-1065.36792
131/ 132	-39.89386	56.67981	-391.85205	1869.73828	1494.67236
132/ 133	-220.43025	-129.35280	-313.87695	463.88550	-199.77441
133/ 134	-43.88165	-127.10625	9.26917	-223.86314	-385.58179
134/ 135	-575.91455	-294.15918	-12.08117	1267.88989	385.73511
135/ 136	-20.83340	-44.49911	-28.08545	495.72095	402.30298
136/ 137	-284.80811	-264.47534	100.59055	-1271.35547	-1720.04834
137/ 138	-45.85832	2.83856	-39.88348	-1596.66504	-1679.56812
138/ 139	21.93256	129.63614	30.53033	272.43164	454.53052
139/ 140	-73.88785	-101.51631	-11.80711	907.68848	720.47705
140/ 141	-11.50390	278.40063	423.67358	-1988.45288	-1297.88257
141/ 142	-248.46025	-477.57690	-504.03931	1684.80273	454.72632
142/ 143	113.95938	504.94702	121.42239	-1420.21021	-679.88159
143/ 144	-46.15230	-212.90662	-369.32861	1281.32813	652.94067
144/ 145	-46.50172	132.47250	147.37013	96.38690	329.72778
145/ 146	-133.24199	-435.86304	-131.17007	1776.19214	1075.91724
146/ 147	-26.56766	795.49683	931.58521	-2287.08276	-586.56860
147/ 148	-15.65540	-882.19507	-415.14380	1470.71948	157.72534
148/ 149	-56.97937	-75.74359	-180.88000	263.29126	-50.31152
149/ 150	69.36746	-142.56670	57.73219	359.86597	344.39893
150/ 151	-236.64766	-289.06006	-176.86743	264.62793	-437.94702
151/ 152	239.61064	367.71851	-400.02539	-1363.85742	-1156.55371
152/ 153	48.34673	162.01459	92.00955	0.0	302.37085
TOTALS	-3328.71582	-3745.13647	-1424.19434	8131.60547	-366.43750

MASS TRANSPORT AT 24 DEGREES SOUTH
UNITS ARE (GRAMS/SEC) X E12

STATION NUMBERS	SURFACE	S.ATLANTIC CENTRAL	ANTARCTIC INTERMED	DEEP AND BOTTOM	STATION TOTAL
416/ 417	0.48135	0.0	0.0	0.0	0.48135
417/ 418	1.33561	0.76649	0.01744	2.16686	4.28641
418/ 419	-2.00308	-1.78394	-0.32559	1.65301	-2.45960
419/ 420	0.10785	-0.25052	-0.13823	2.20063	1.91973
420/ 421	0.55757	0.96046	0.31375	0.99558	2.82736
421/ 422	-0.62353	-0.67545	-0.18551	5.64439	4.15992
422/ 423	0.66909	0.88382	0.16376	-0.91304	0.80362
423/ 424	0.12620	0.13493	0.07968	0.23319	0.57400
424/ 425	-0.42064	-0.66338	-0.27624	1.13080	-0.22946
425/ 426	0.16609	0.15093	0.11127	3.49478	3.92307
426/ 427	0.94709	1.09620	0.29173	-4.45880	-2.12378
427/ 428	-0.70515	-1.01515	-0.42149	3.32922	1.18743
428/ 429	-2.22059	-2.07433	-0.31129	2.81368	-1.79252
429/ 430	0.44929	0.62766	0.22020	-1.71584	-0.41869
430/ 431	0.02333	-0.30829	0.03728	-0.06425	-0.31193
431/ 432	0.60635	0.85762	-0.01772	-0.01390	1.43235
432/ 433	0.40711	0.02214	-0.04072	-1.57722	-1.18869
433/ 434	1.42114	3.32220	0.82715	-11.16892	-5.59844
434/ 435	-0.27182	-0.18416	0.02429	-0.30338	-0.73506
435/ 436	-2.59071	-5.52562	-1.13213	12.90135	3.65288
436/ 437	0.29147	0.09115	-0.05096	1.91387	2.24553
437/ 438	0.20071	-0.51248	-0.10155	-4.19588	-4.60921
438/ 439	-0.27849	-0.02347	0.07722	-1.03959	-1.26434
439/ 440	-0.73001	-0.70768	0.22137	6.82220	5.60589
440/ 441	-0.29948	-0.85861	-0.64555	0.02919	-1.77445
441/ 442	-0.15835	-1.00896	-0.37159	-3.17634	-4.71523
442/ 443	0.14691	-0.04667	0.18404	-2.74655	-2.46230
443/ 444	-0.19728	1.25529	0.43742	-5.03234	-3.53691
444/ 445	-0.06810	-0.41340	-0.01219	10.97920	10.48551
445/ 446	-0.95243	-2.47724	-0.58786	-4.49982	-8.51734
446/ 447	0.20443	0.80348	-0.56477	5.12111	5.56426
447/ 448	-0.02529	-0.24264	0.08537	0.68405	0.50149
448/ 449	0.0	0.14606	0.38563	1.07406	1.60575
449/ 450	0.0	-4.24921	-1.06472	0.14821	-5.16572
450/ 451	0.0	-2.05579	-0.20883	0.34326	-1.92137
451/ 452	0.0	-1.67567	-0.71652	0.91778	-1.47441
452/ 453	0.0	-0.47842	-0.00922	-0.60075	-1.08839
453/ 454	0.0	-0.02970	0.80200	-5.13293	-4.36063
454/ 455	0.0	-0.95198	0.31102	5.60803	4.96706
455/ 456	0.0	0.48937	0.60039	-1.21270	-0.12294
456/ 457	0.0	-0.03098	0.0	0.0	-0.03098
457/ 458	0.0	-0.34631	0.0	0.0	-0.34631
TOTALS	-3.40335	-16.98189	-1.99157	22.35007	-0.02672

SALT TRANSPORT AT 24 DEGREES SOUTH
UNITS ARE (GRAMS/SEC) X E12

STATION NUMBERS	SURFACE	S.ATLANTIC CENTRAL	ANTARCTIC INTERMED	DEEP AND BOTTOM	STATION TOTAL
416/ 417	17.60094	0.0	0.0	0.0	17.60094
417/ 418	48.93596	27.22797	0.73153	75.43556	152.33101
418/ 419	-73.32178	-62.92258	-11.17383	57.72702	-89.69116
419/ 420	3.96438	-8.74070	-4.75003	76.87279	67.34644
420/ 421	20.36931	33.70891	10.78915	34.79819	99.66554
421/ 422	-22.74612	-23.72711	-6.34861	197.03711	144.21527
422/ 423	24.40808	31.07333	5.61719	-31.83580	29.26280
423/ 424	4.58080	4.75990	2.74747	8.25204	20.34019
424/ 425	-15.30823	-23.32878	-9.50276	39.42769	-8.71207
425/ 426	6.04934	5.33453	3.84947	122.11487	137.34821
426/ 427	34.63931	38.60097	10.01576	-155.52571	-72.26968
427/ 428	-25.78371	-35.68939	-14.49388	115.83717	39.87019
428/ 429	-80.89262	-72.96606	-10.71191	98.12561	-66.44498
429/ 430	16.40399	22.08351	7.56500	-59.86214	-13.80965
430/ 431	0.86260	-10.82203	1.30110	-2.20632	-10.86466
431/ 432	22.13593	30.13521	-0.61297	-0.55311	51.10504
432/ 433	14.87630	0.83355	-1.41643	-54.97392	-40.68050
433/ 434	51.65364	116.79108	28.43686	-389.65308	-192.77150
434/ 435	-9.87055	-6.62951	0.83545	-10.58588	-26.25047
435/ 436	-93.99510	-194.33850	-38.88293	450.01978	122.80347
436/ 437	10.56227	3.28801	-1.74586	66.73004	78.83446
437/ 438	7.29107	-18.00699	-3.51945	-146.24622	-160.48158
438/ 439	-10.11004	-0.87731	2.65603	-36.24149	-44.57280
439/ 440	-26.46388	-24.99591	7.62621	237.88860	194.05502
440/ 441	-10.83243	-30.01860	-22.18008	1.01022	-62.02089
441/ 442	-5.70635	-35.36064	-12.77644	-110.83195	-164.67537
442/ 443	5.29234	-1.63691	6.32582	-95.77789	-85.79663
443/ 444	-7.09476	43.90761	15.04726	-175.53114	-123.67104
444/ 445	-2.44672	-14.49466	-0.41464	383.00220	365.64600
445/ 446	-34.16794	-87.08459	-20.22766	-156.99063	-298.47070
446/ 447	7.31878	28.48268	-19.43073	178.62202	194.99275
447/ 448	-0.90328	-8.52919	2.93657	23.86990	17.37399
448/ 449	0.0	5.04076	13.26488	37.47421	55.77985
449/ 450	0.0	-149.57614	-36.62471	5.15761	-181.04324
450/ 451	0.0	-72.32664	-7.18282	11.95441	-67.55505
451/ 452	0.0	-58.80598	-24.66295	32.00357	-51.46536
452/ 453	0.0	-16.78940	-0.31797	-20.93132	-38.03868
453/ 454	0.0	-1.13168	27.62723	-179.02229	-152.52675
454/ 455	0.0	-33.42223	10.72472	195.61696	172.91946
455/ 456	0.0	16.99942	20.70006	-42.16980	-4.47032
456/ 457	0.0	-1.10130	0.0	0.0	-1.10130
457/ 458	0.0	-12.12368	0.0	0.0	-12.12368
TOTALS	-122.69826	-597.16504	-68.17680	779.98511	-8.05493

HEAT TRANSPORT AT 24 DEGREES SOUTH
UNITS ARE (CAL/SEC) X E12

STATION NUMBERS	SURFACE	S.ATLANTIC CENTRAL	ANTARCTIC INTERMED	DEEP AND BOTTOM	STATION TOTAL
416/ 417	141.85873	0.0	0.0	0.0	141.85873
417/ 418	393.67261	220.91554	4.25894	599.89355	1218.74048
418/ 419	-590.01587	-510.75342	-90.59940	457.22705	-734.14160
419/ 420	31.85185	-71.02339	-38.45644	608.79956	531.17139
420/ 421	164.03520	273.78296	87.30933	275.26172	800.38916
421/ 422	-183.34219	-192.69662	-51.77365	1557.77612	1129.96387
422/ 423	196.75793	252.43646	45.60780	-251.92639	242.87561
423/ 424	36.96672	38.64598	22.13287	65.79753	163.54311
424/ 425	-123.51422	-189.49234	-76.79193	311.20508	-78.59302
425/ 426	48.75931	43.30463	30.82079	965.86768	1088.75220
426/ 427	278.53931	313.51807	81.33212	-1229.45410	-556.06470
427/ 428	-207.36304	-289.93506	-117.36864	914.90210	300.23560
428/ 429	-651.84961	-592.89722	-86.51683	774.96558	-556.29785
429/ 430	132.10126	179.35757	61.15977	-472.98047	-100.36206
430/ 431	6.91063	-87.97279	10.28876	-16.99371	-87.76712
431/ 432	178.07684	244.94823	-4.84501	-4.82738	413.35229
432/ 433	119.62230	6.71568	-11.27787	-434.45361	-319.39331
433/ 434	416.37842	949.07275	230.62048	-3079.73535	-1483.66382
434/ 435	-79.63168	-53.75102	6.75097	-84.27568	-210.90741
435/ 436	-758.78613	-1579.25586	-315.31909	3558.84106	905.47998
436/ 437	85.29866	26.68149	-14.24224	528.09033	625.82813
437/ 438	58.90500	-146.39264	-28.24284	-1157.60571	-1273.33618
438/ 439	-81.67590	-7.12604	21.53563	-286.74561	-354.01172
439/ 440	-213.68202	-203.13364	61.41359	1880.88940	1525.43779
440/ 441	-87.55095	-243.98799	-179.40488	8.09239	-502.85107
441/ 442	-46.22054	-287.48730	-103.22505	-875.26563	-1312.19824
442/ 443	42.96507	-13.32710	51.15691	-757.55396	-676.75903
443/ 444	-57.64406	357.08252	121.59521	-1387.66260	-966.62915
444/ 445	-19.86240	-117.85931	-3.49090	3026.84644	2885.63379
445/ 446	-277.57104	-708.20630	-163.50920	-1240.29346	-2389.57983
446/ 447	59.58835	231.65009	-156.78642	1412.06958	1546.52124
447/ 448	-7.36216	-69.40044	23.63605	188.42033	135.29379
448/ 449	0.0	40.95065	107.14294	296.02783	444.12134
449/ 450	0.0	-1217.59570	-295.78174	40.96808	-1472.40918
450/ 451	0.0	-589.12769	-58.17427	94.86038	-552.44116
451/ 452	0.0	-479.26416	-199.18843	253.37944	-425.07275
452/ 453	0.0	-136.93535	-2.58561	-165.43340	-304.95435
453/ 454	0.0	-9.54039	222.70317	-1416.09473	-1202.93188
454/ 455	0.0	-273.07568	86.50745	1547.77563	1361.20728
455/ 456	0.0	137.98619	167.15346	-335.15356	-30.01392
456/ 457	0.0	-9.15942	0.0	0.0	-9.15942
457/ 458	0.0	-99.15234	0.0	0.0	-99.15234
TOTALS	-993.78101	-4861.37500	-554.42651	6170.85547	-238.72266

MASS TRANSPORT AT 32 DEGREES SOUTH
UNITS ARE (GRAMS/SEC) X E12

STATION NUMBERS	SURFACE	S.ATLANTIC CENTRAL	ANTARCTIC INTERMED	DEEP AND BOTTOM	STATION TOTAL
5806/5807	0.02668	0.01883	0.0	0.0	0.04551
5807/5808	0.39893	-0.86446	-7.58216	0.0	-8.04768
5808/5798	1.77983	2.38966	-2.94696	-7.91289	-6.69037
5798/5809	-1.31176	-1.88529	0.20091	14.90786	11.91173
5809/5810	-0.51836	-1.59057	-0.31133	-0.98032	-3.40058
5810/5811	0.28072	-0.42492	-0.49869	2.26465	1.62176
5811/5812	-0.86491	-1.93829	0.20423	9.43033	6.83136
5812/5813	-0.46759	-1.84566	-0.37578	4.17801	1.48899
5813/5814	0.88657	2.39738	0.48392	-3.17673	0.59114
5814/5815	0.47347	1.83394	0.65624	1.02490	3.98854
5815/5816	-1.25774	-3.36234	-0.85466	0.96105	-4.51370
5816/5817	-0.17430	-0.73030	-0.40479	1.33746	0.02807
5817/5818	0.90245	3.52182	0.56377	-6.17936	-1.19132
5818/5819	0.14872	-0.15775	0.17997	3.42773	3.59867
5819/5820	-0.82534	-2.18155	-0.45299	3.37515	-0.08473
5820/5821	-0.09310	-0.84222	-0.19673	-1.99212	-3.12417
5821/5822	-0.56934	-1.91958	-0.26407	4.31188	1.55890
5822/5823	0.59515	1.93867	0.35179	1.86308	4.74868
5823/5824	-0.48331	-1.62740	-0.47668	0.25703	-2.33036
5824/5825	0.80937	2.00408	0.43422	-0.62134	2.62633
5825/5826	-0.36868	-0.59410	-0.13415	-0.56512	-1.66205
5826/5827	-0.74264	-2.20184	-0.35671	3.51453	0.21334
5827/5828	0.56079	0.67116	-0.03483	-1.80699	-0.60988
5828/5829	-0.75966	-1.36039	-0.43593	2.87359	0.31762
5829/5830	2.48536	8.51403	1.68626	-4.74350	7.94216
5830/5831	-1.72282	-5.73637	-0.79526	4.43976	-3.81468
5831/5832	0.43923	0.23147	-0.24518	-3.54718	-3.12165
5832/5843	-0.48550	-0.45785	-0.18615	-6.39681	-7.52630
5843/5842	0.0	11.75444	0.99507	-10.56445	2.18506
5842/5841	0.0	-13.51068	-1.05468	10.65057	-3.91479
5841/5840	0.0	3.54868	0.40271	4.10130	8.05269
5840/5839	0.0	10.36933	0.45063	6.96529	17.78525
5839/5838	0.0	-21.83522	-2.60653	13.63280	-10.80894
5838/5837	0.0	-1.01260	-0.02469	-2.19850	-3.23579
5837/5836	0.0	-5.21178	-2.38014	0.0	-7.59192
5836/5835	0.0	-2.52367	-0.77254	0.0	-3.29621
5835/5834	0.0	-0.17870	0.0	0.0	-0.17870
5834/5833	0.0	-0.37305	0.0	0.0	-0.37305
TOTALS	-0.85776	-25.17276	-16.78152	42.82959	0.01755

HEAT TRANSPORT AT 32 DEGREES SOUTH
UNITS ARE (CAL/SEC) X E12

STATION NUMBERS	SURFACE	S.ATLANTIC CENTRAL	ANTARCTIC INTERMED	DEEP AND BOTTOM	STATION TOTAL
5806/5807	7.89299	5.45182	0.0	0.0	13.34481
5807/5808	116.81583	-239.16728	-2107.31152	0.0	-2229.66284
5808/5798	522.80273	682.69702	-813.21094	-2186.94629	-1794.65747
5798/5809	-385.48584	-539.80811	53.36559	4113.68750	3241.75928
5809/5810	-152.32939	-455.08569	-86.62642	-268.94653	-962.98779
5810/5811	82.45547	-121.11714	-138.51523	622.65063	445.47363
5811/5812	-253.95515	-555.87598	55.79169	2598.38013	1844.34082
5812/5813	-137.07677	-528.39673	-104.94354	1152.00635	381.58960
5813/5814	260.50415	685.33398	134.78795	-876.64990	203.97607
5814/5815	139.39397	524.85034	182.31639	282.75977	1129.32007
5815/5816	-369.22363	-962.35229	-237.61488	264.79858	-1304.39209
5816/5817	-50.98161	-208.74448	-112.67882	368.91772	-3.48706
5817/5818	264.38037	1006.02856	157.75267	-1704.29883	-276.13745
5818/5819	43.62332	-44.88438	49.83173	944.11426	992.68481
5819/5820	-241.84532	-623.85400	-126.59692	930.34888	-61.94727
5820/5821	-27.22726	-240.35817	-54.57797	-549.06885	-871.23193
5821/5822	-166.37627	-548.30688	-73.73882	1188.55762	400.13574
5822/5823	173.94939	554.11743	97.94905	513.69141	1339.70703
5823/5824	-141.41956	-464.78491	-132.59651	70.91562	-667.88501
5824/5825	237.17479	573.05249	120.82130	-171.38309	759.66504
5825/5826	-107.93678	-170.09528	-37.27264	-155.82515	-471.12939
5826/5827	-216.76987	-628.94507	-99.64769	968.80225	23.43994
5827/5828	163.75441	192.32199	-9.58678	-497.99243	-151.50317
5828/5829	-221.76534	-388.43262	-121.09924	791.95801	60.66113
5829/5830	725.08154	2433.62085	469.50903	-1307.49854	2320.71289
5830/5831	-502.29175	-1641.00684	-221.39642	1223.64331	-1141.05151
5831/5832	128.15300	67.32317	-68.38579	-973.32275	-846.23218
5832/5843	-141.39943	-130.66617	-51.40309	-1762.42798	-2085.89648
5843/5842	0.0	3370.93311	277.20215	-2905.45996	742.67529
5842/5841	0.0	-3871.90967	-294.26172	2932.18262	-1233.98535
5841/5840	0.0	1019.36694	112.48276	1126.81470	2258.66431
5840/5839	0.0	2991.36328	125.17450	1914.23901	5030.77344
5839/5838	0.0	-6274.52734	-726.41821	3757.32495	-3243.62036
5838/5837	0.0	-289.53442	-7.00433	-606.29297	-902.83154
5837/5836	0.0	-1485.10742	-660.66748	0.0	-2145.77490
5836/5835	0.0	-719.53125	-214.81793	0.0	-934.34912
5835/5834	0.0	-51.19756	0.0	0.0	-51.19756
5834/5833	0.0	-106.97672	0.0	0.0	-106.97672
TOTALS	-250.10114	-7184.11323	-4663.28906	11799.19141	-298.30859

SALT TRANSPORT AT 32 DEGREES SOUTH
UNITS ARE (GRAMS/SEC) X E12

STATION NUMBERS	SURFACE	S.ATLANTIC CENTRAL	ANTARCTIC INTERMED	DEEP AND BOTTOM	STATION TOTAL
5806/5807	0.94697	0.67367	0.0	0.0	1.62064
5807/5808	14.41425	-29.38832	-260.27417	0.0	-275.24805
5808/5798	64.55176	84.15514	-101.71237	-274.70801	-227.71349
5798/5809	-47.40367	-66.55685	7.24112	520.15234	413.43286
5809/5810	-18.58302	-56.07300	-10.64452	-34.07590	-119.37643
5810/5811	10.04528	-14.91847	-17.12022	78.79909	56.80568
5811/5812	-30.96283	-68.51729	7.18168	328.60425	236.30582
5812/5813	-16.75737	-65.11526	-12.81104	145.67914	50.99547
5813/5814	31.69489	84.39919	16.51811	-110.79820	21.81398
5814/5815	16.92403	64.63702	22.57396	35.73810	139.87311
5815/5816	-44.85979	-118.58821	-29.35335	33.51051	-159.29083
5816/5817	-6.20685	-25.72887	-13.84793	46.61902	0.83537
5817/5818	32.18280	123.91728	19.17863	-215.46359	-40.18488
5818/5819	5.31000	-5.52607	6.19613	119.45712	125.43718
5819/5820	-29.44447	-76.81383	-15.43232	117.64377	-4.04684
5820/5821	-3.31359	-29.59402	-6.76785	-69.44020	-109.11565
5821/5822	-20.21886	-67.46516	-8.98991	150.23067	53.55673
5822/5823	21.18558	68.17140	12.05317	64.97903	166.38918
5823/5824	-17.25658	-57.19650	-16.32420	8.94073	-81.83655
5824/5825	28.99538	70.50047	14.88324	-21.62999	92.74910
5825/5826	-13.20458	-20.92128	-4.60142	-19.68629	-58.41356
5826/5827	-26.46233	-77.35393	-12.20549	122.47572	6.45398
5827/5828	20.00890	23.62344	-1.17936	-62.99521	-20.54224
5828/5829	-27.14435	-47.72336	-14.98012	100.15372	10.30589
5829/5830	88.77379	299.08081	57.84822	-165.26056	280.44189
5830/5831	-61.47504	-201.63470	-27.29082	154.73531	-135.66508
5831/5832	15.68396	8.25617	-8.38248	-123.40042	-107.84277
5832/5843	-17.34787	-16.05705	-6.45308	-222.91550	-262.77344
5843/5842	0.0	414.29297	34.11153	-367.73291	80.67139
5842/5841	0.0	-475.60938	-36.07991	370.87378	-140.81543
5841/5840	0.0	125.11162	13.79073	142.73933	281.64160
5840/5839	0.0	366.81958	15.51948	242.53879	624.87744
5839/5838	0.0	-769.33105	-89.62100	475.15698	-383.79492
5838/5837	0.0	-35.50725	-0.85361	-76.63504	-112.99588
5837/5836	0.0	-182.31944	-81.80940	0.0	-264.12866
5836/5835	0.0	-88.32083	-26.56882	0.0	-114.88965
5835/5834	0.0	-6.27320	0.0	0.0	-6.27320
5834/5833	0.0	-13.08676	0.0	0.0	-13.08676
TOTALS	-29.92361	-881.97144	-576.14258	1494.25366	6.21606

APPENDIX B

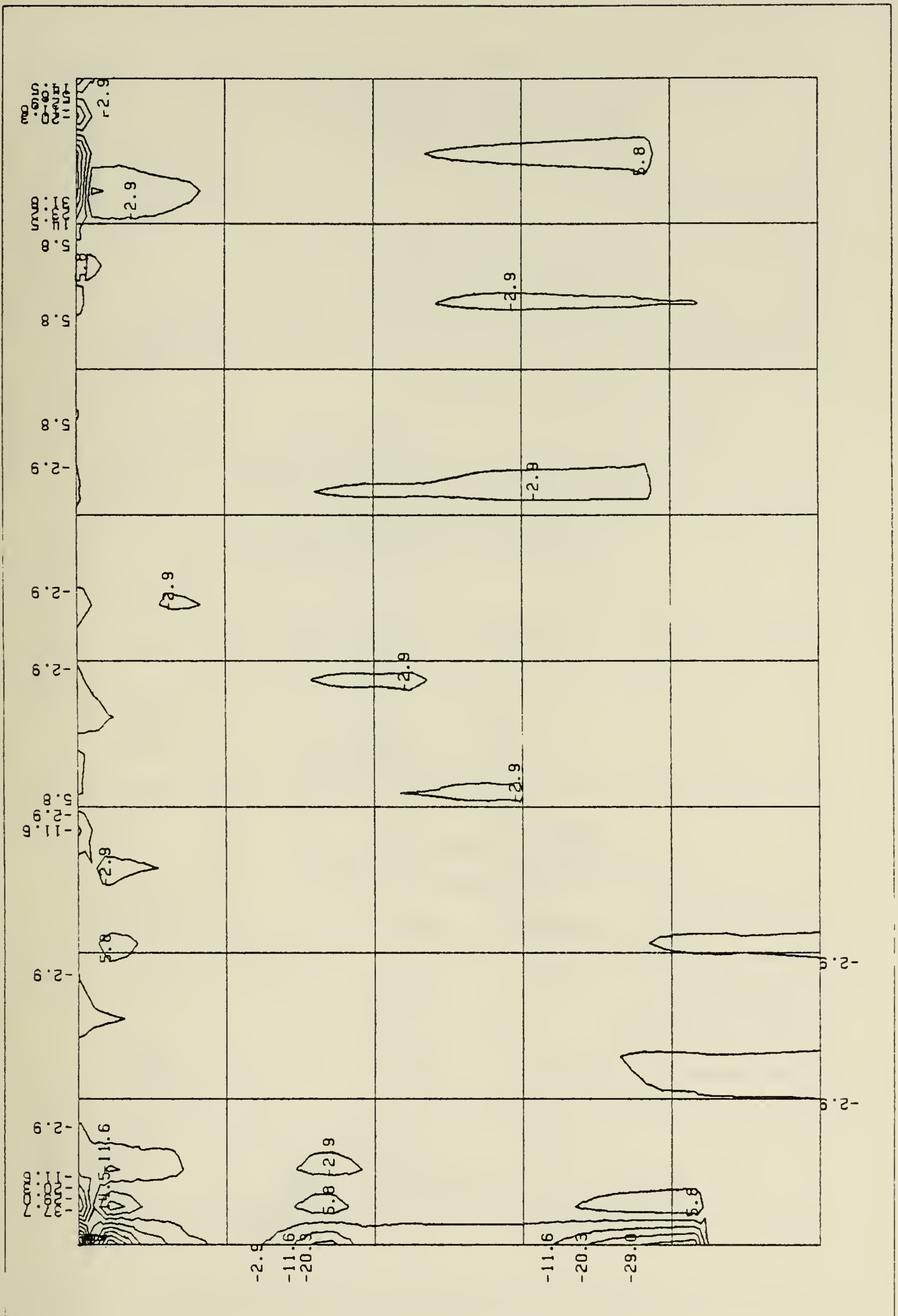
VERTICAL CROSS SECTIONS

Appendix B illustrates vertical cross sections of velocity, and transports of mass, salt, and heat for each latitude. These data were first interpolated to a rectangular grid covering the cross section by a computer subroutine named IBCIEU and then contoured by a subroutine named CONTUR. In executing CONTUR, the data field was first scanned for the highest and lowest values and then contour levels were drawn between them at thirteen intervals. The central values of maxima or minima were labeled, as were exterior contour segments. Since the contour intervals are determined by a data scan in each case, they are not identical for each chart but can be determined from the labels.

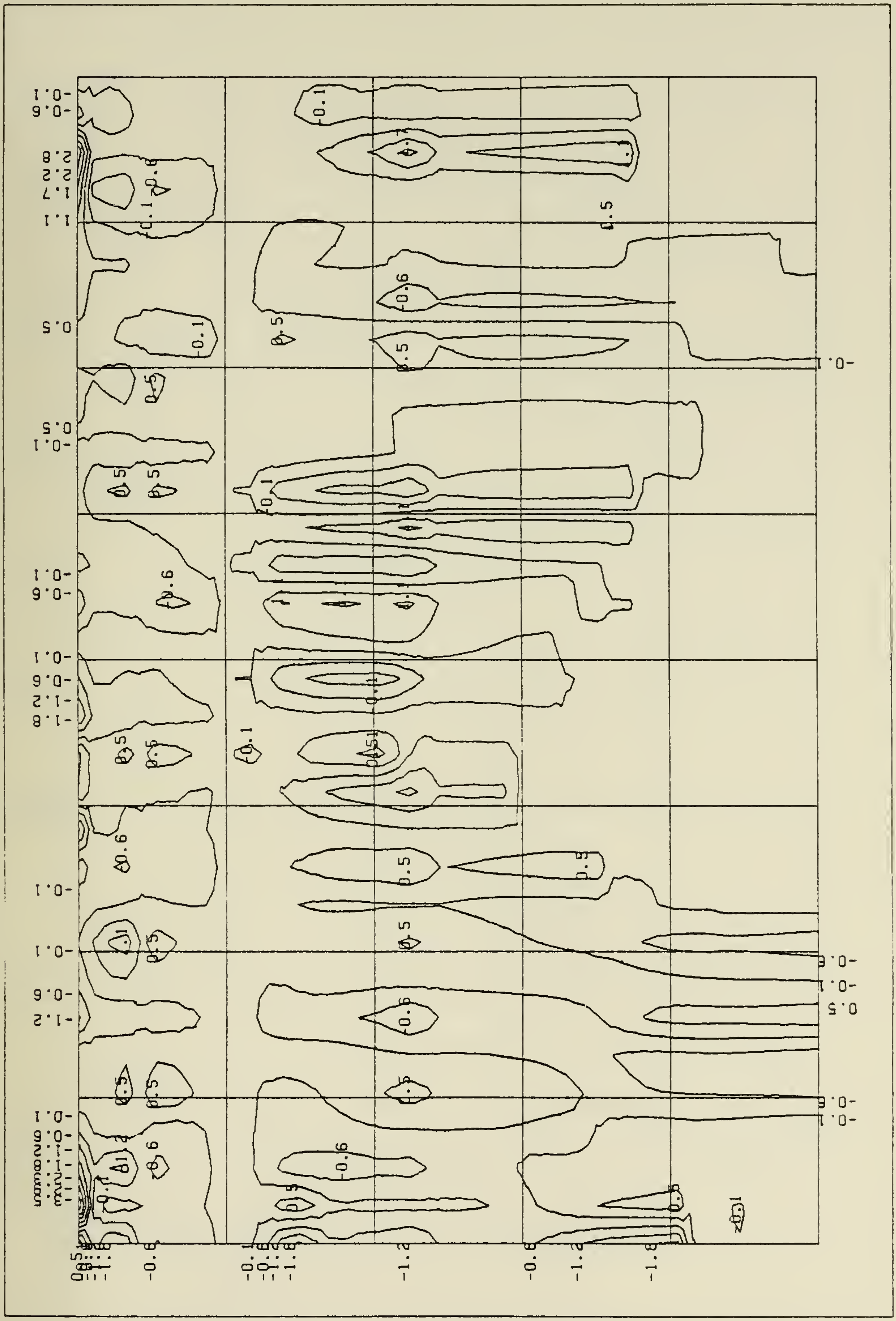
The one-inch grid superimposed on the diagrams represents depths in the vertical of 50, 1084, 2118, 3152, 4186, and 5220 meters for every chart. However, the horizontal extent represents the length of the ship's track and is different for each latitude. The values in kilometers per inch for 8°S, 16°S, 24°S, and 32°S are 163, 290, 314, and 169 respectively.

Units are: velocity, cm/sec; mass transport, gm/sec x 10^2; salt transport, gm/sec x 10^9; and heat transport, cal/sec x 10^9.

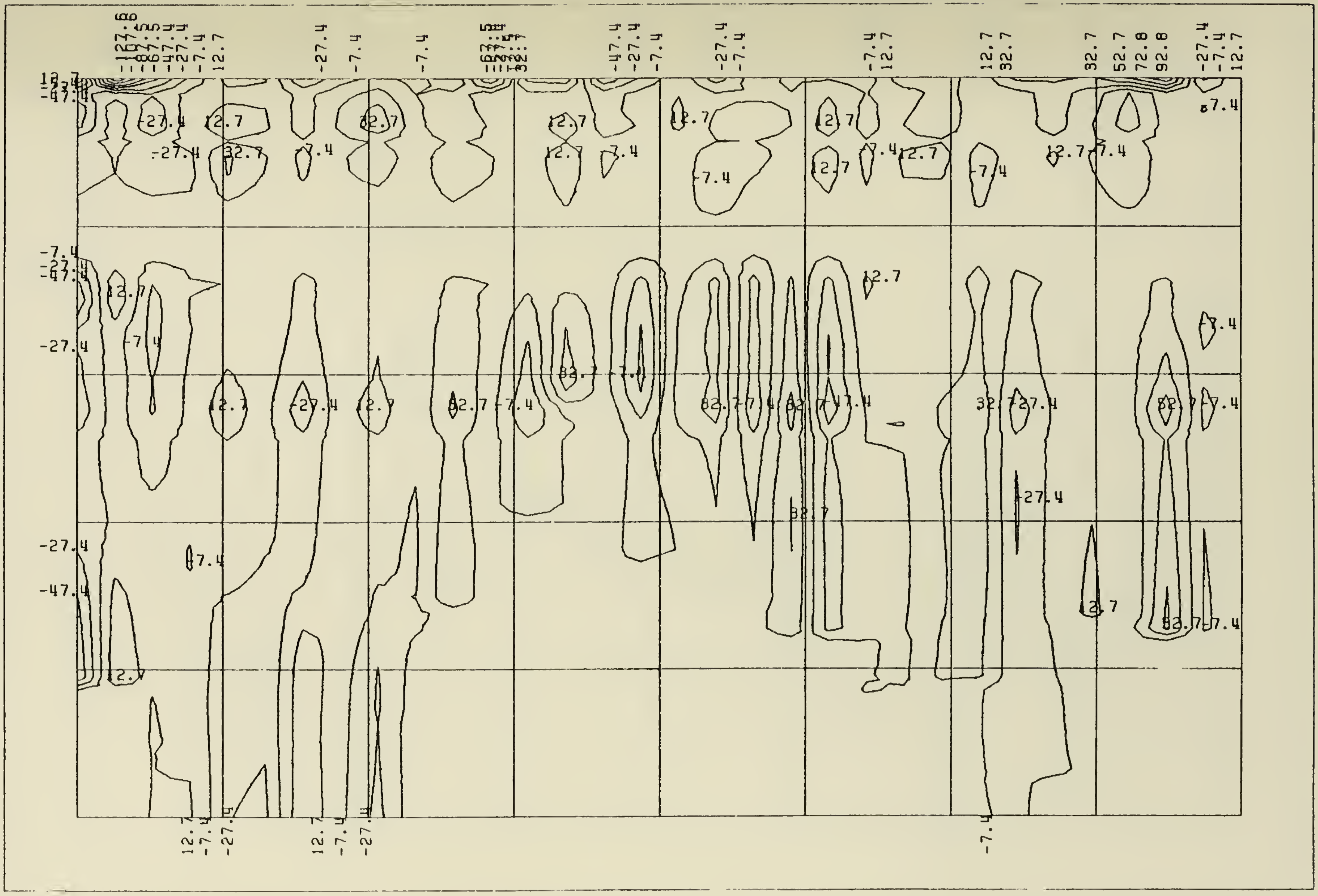
Negative values indicate northward transports.



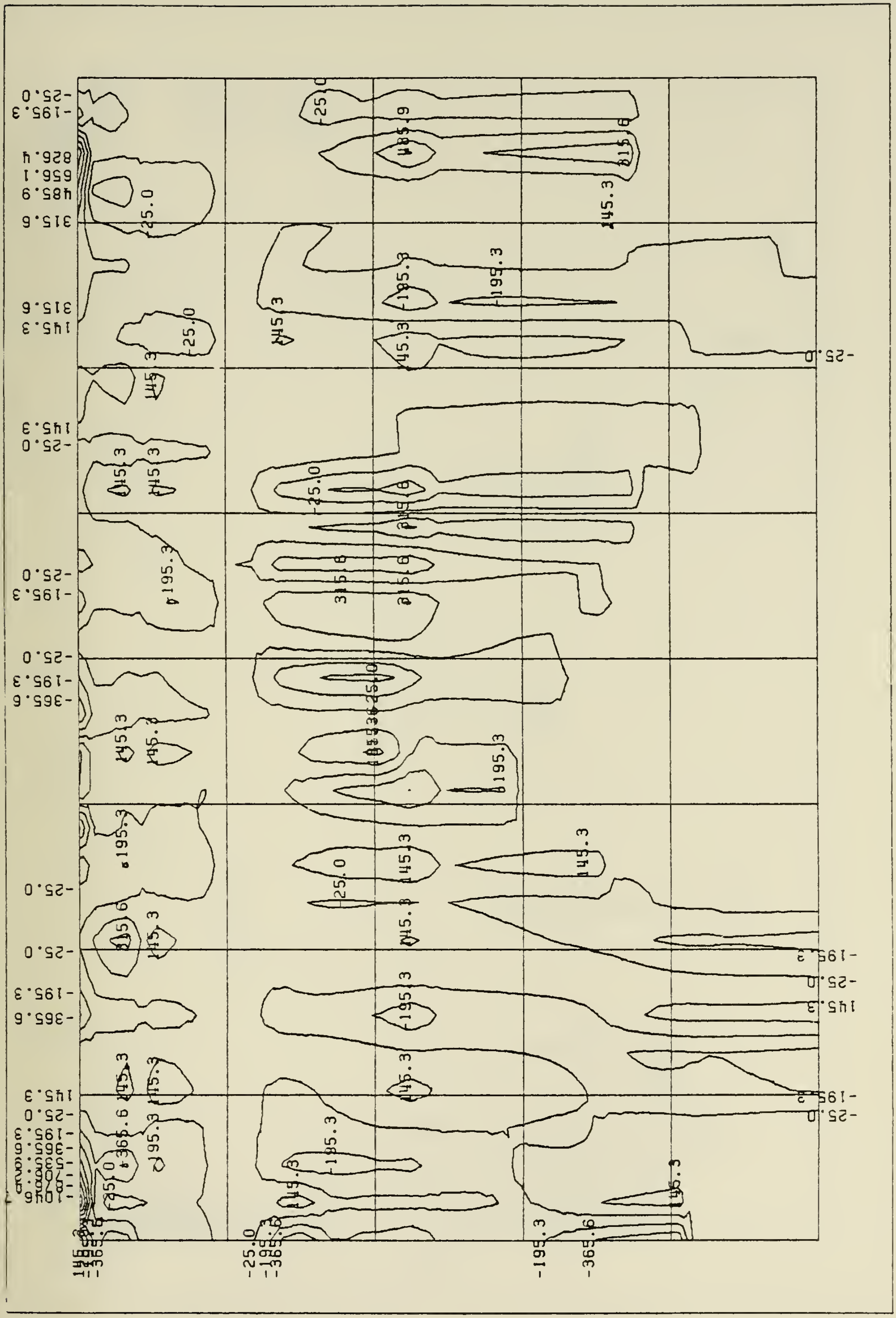
8°S VELOCITY



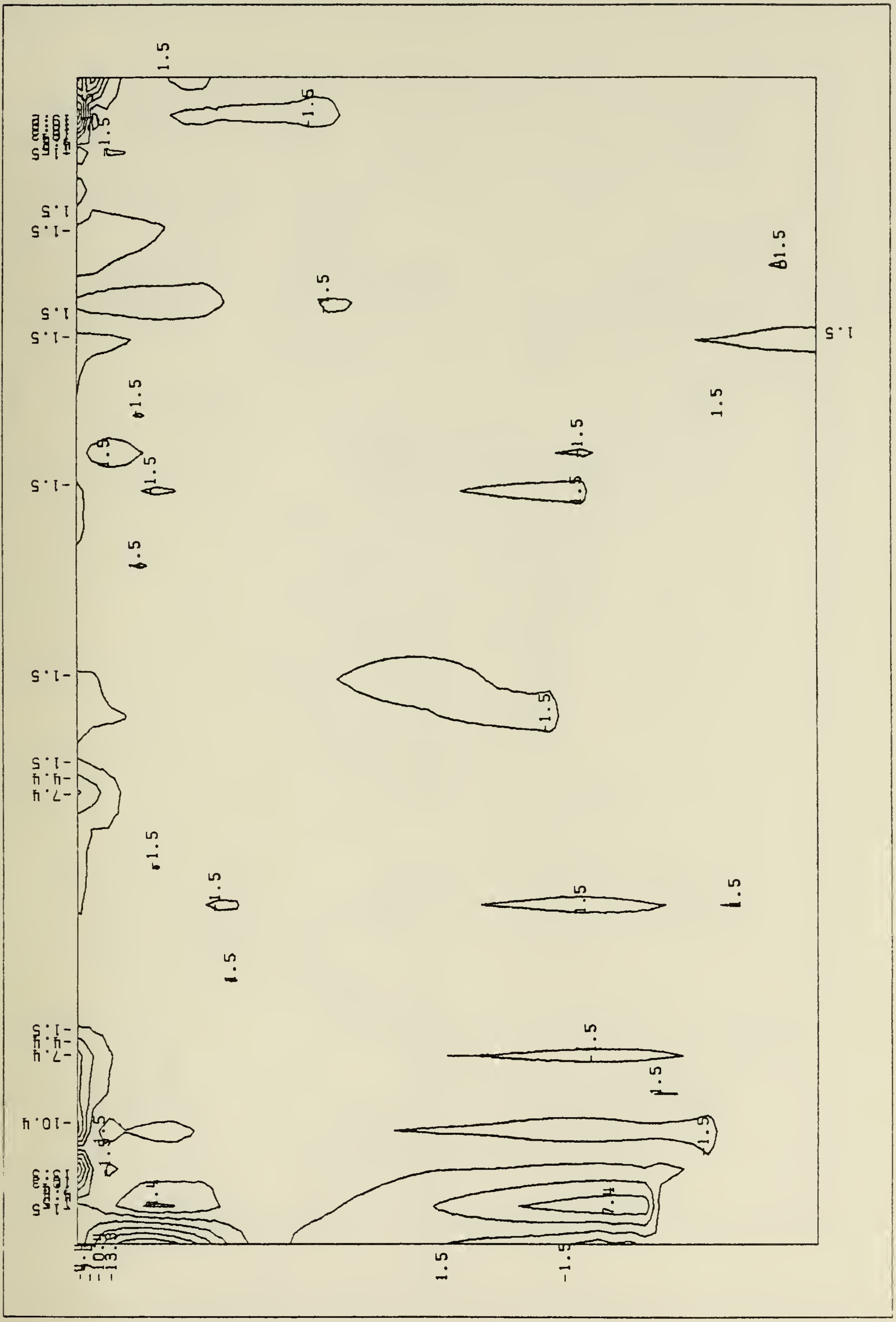
8°S MASS TRANSPORT



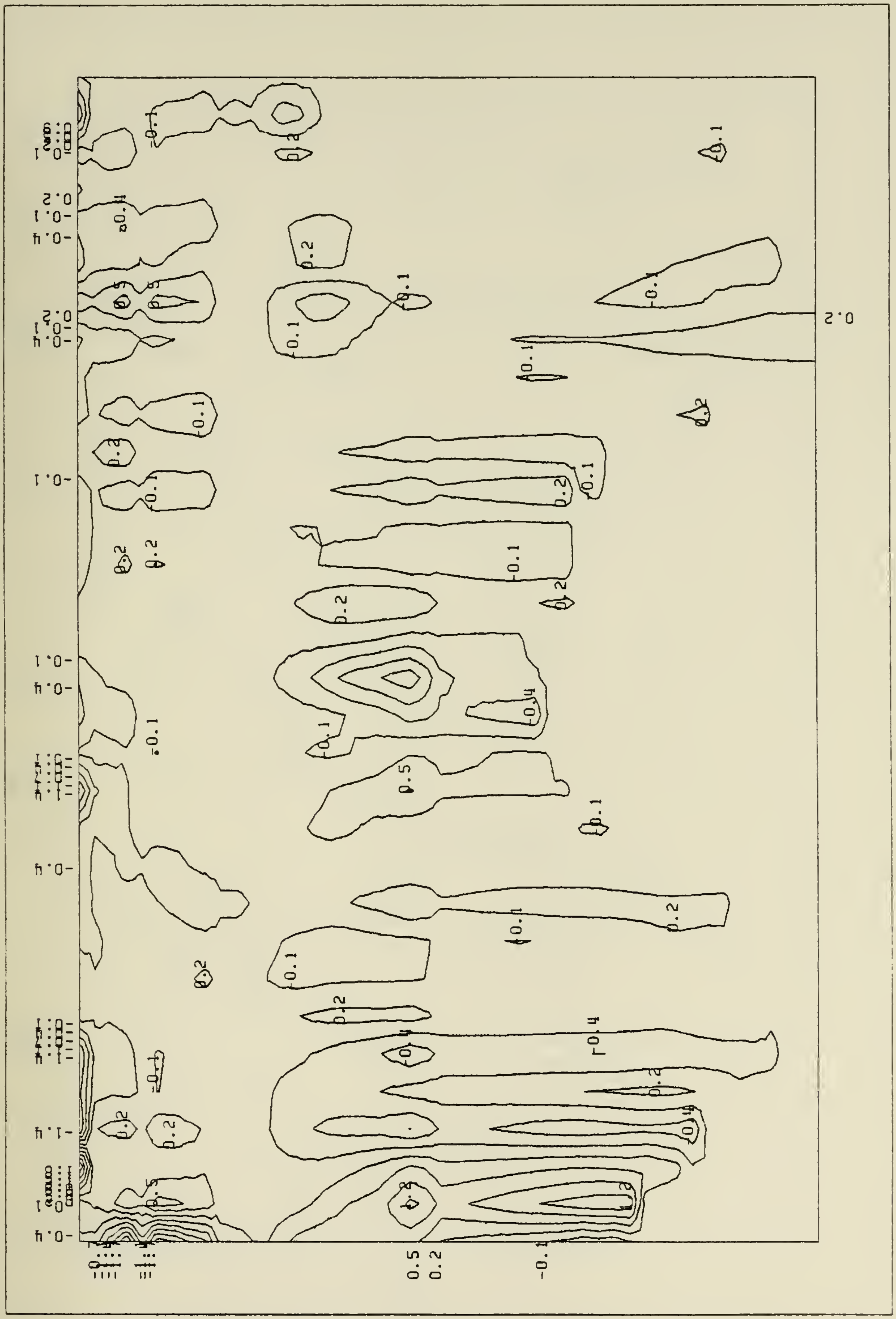
8°S SALT TRANSPORT



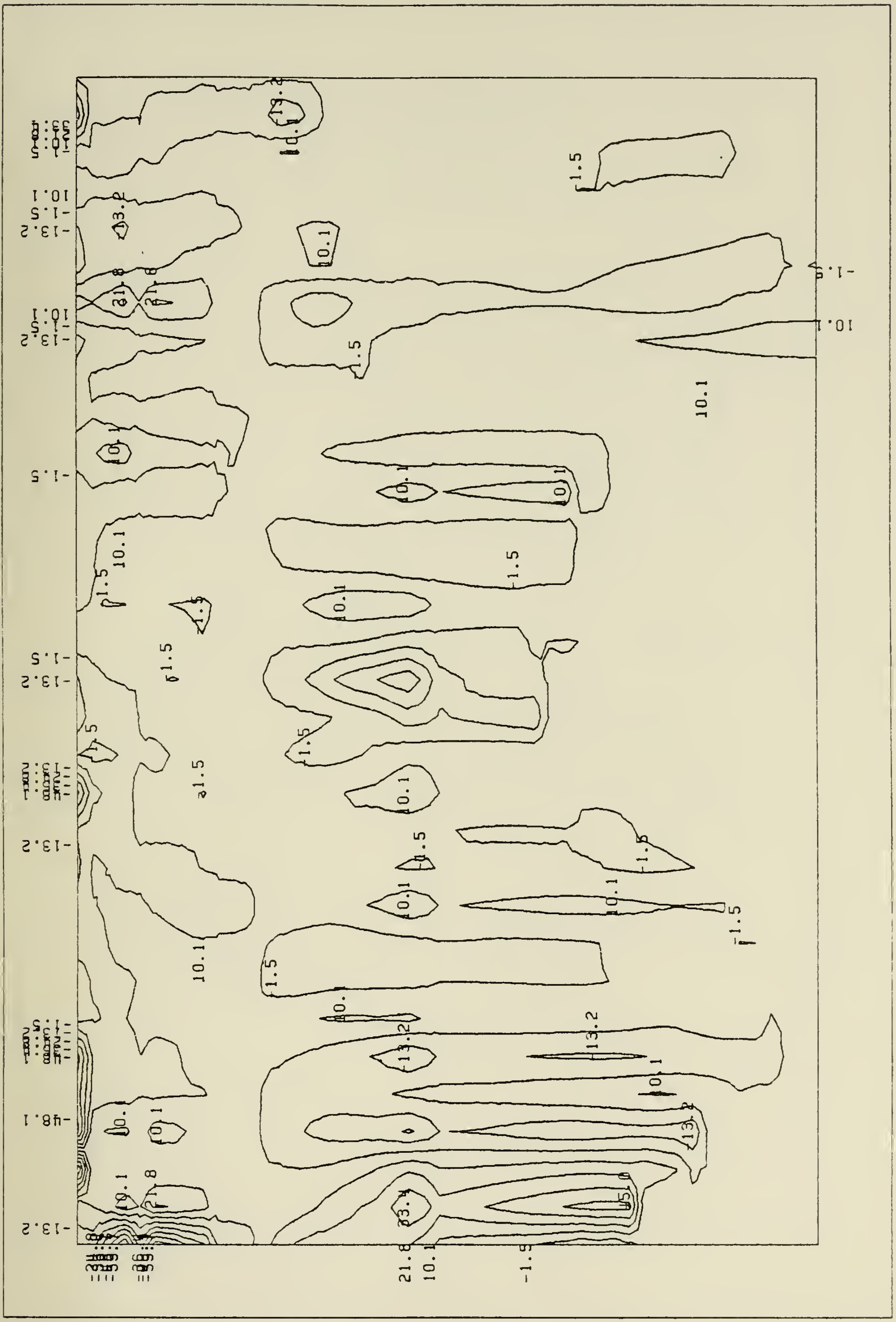
8°S HEAT TRANSPORT



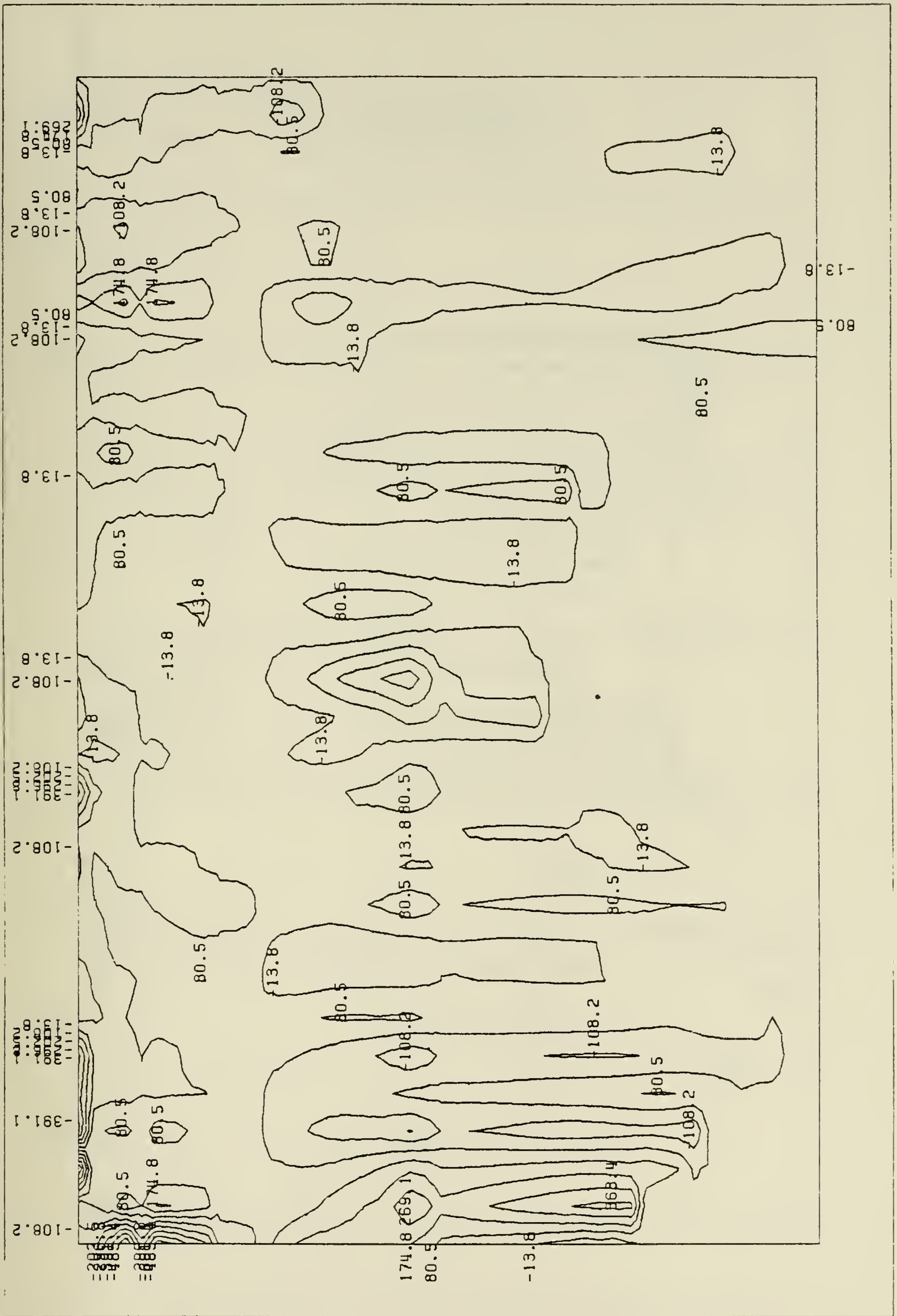
16°S VELOCITY



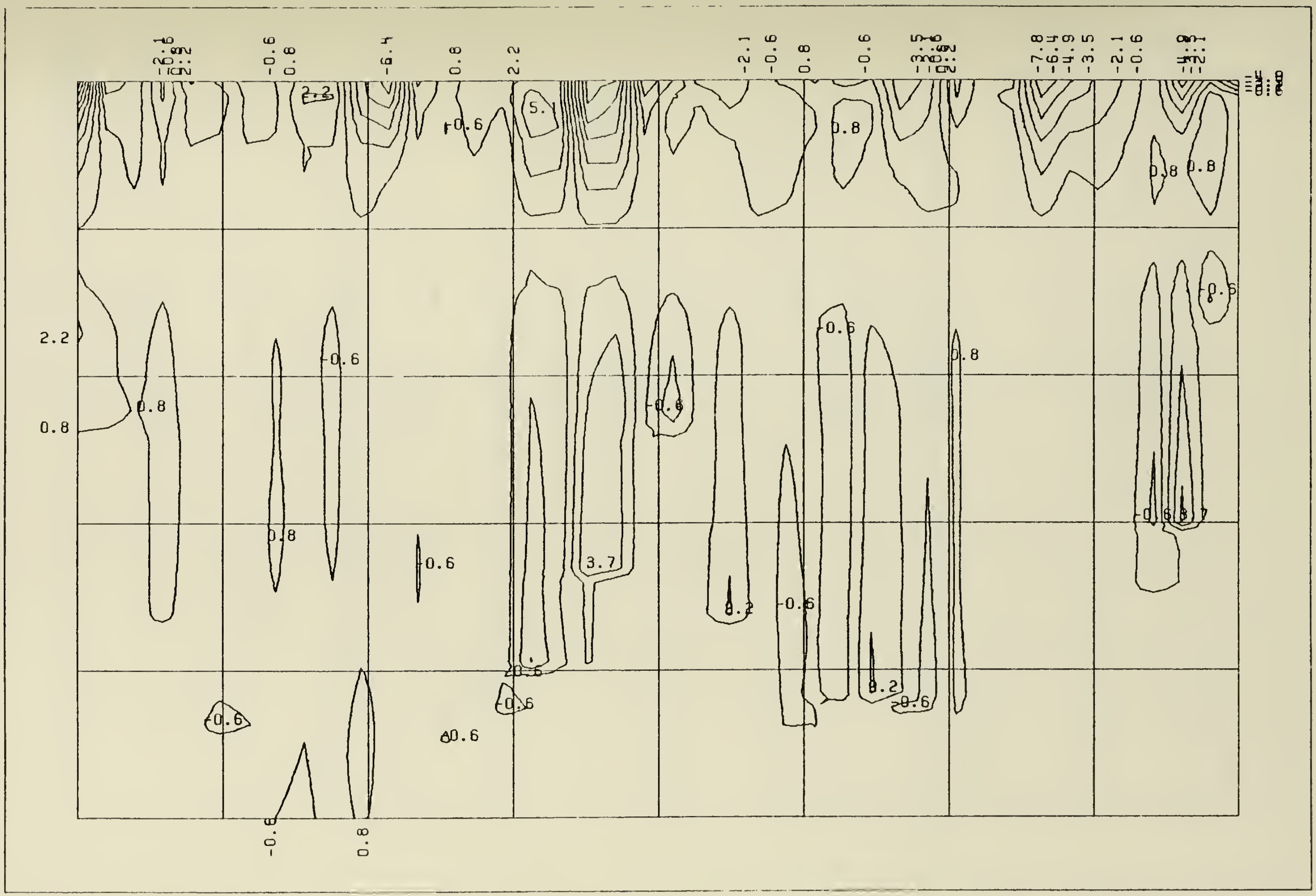
16°S MASS TRANSPORT



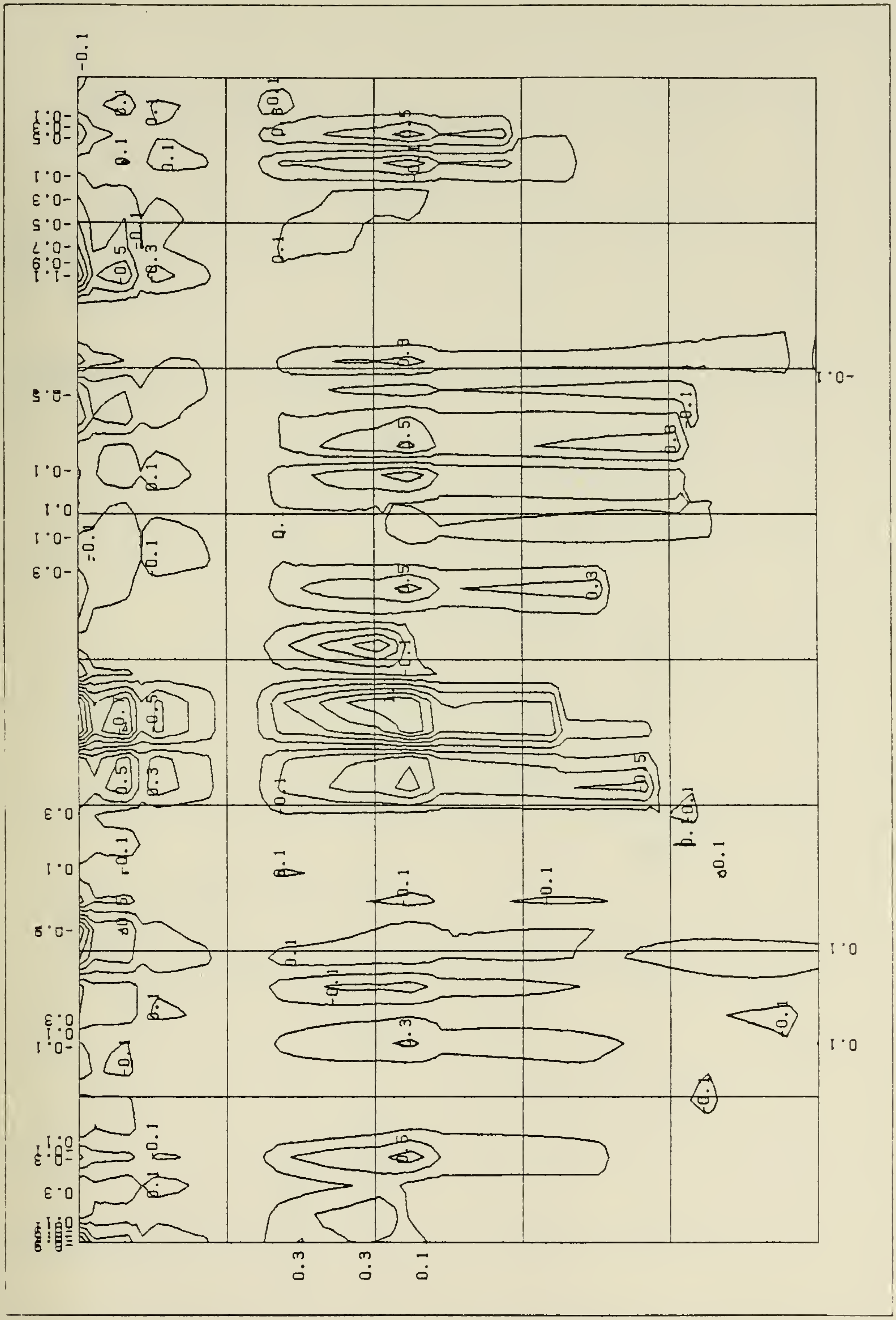
16°S SALT TRANSPORT



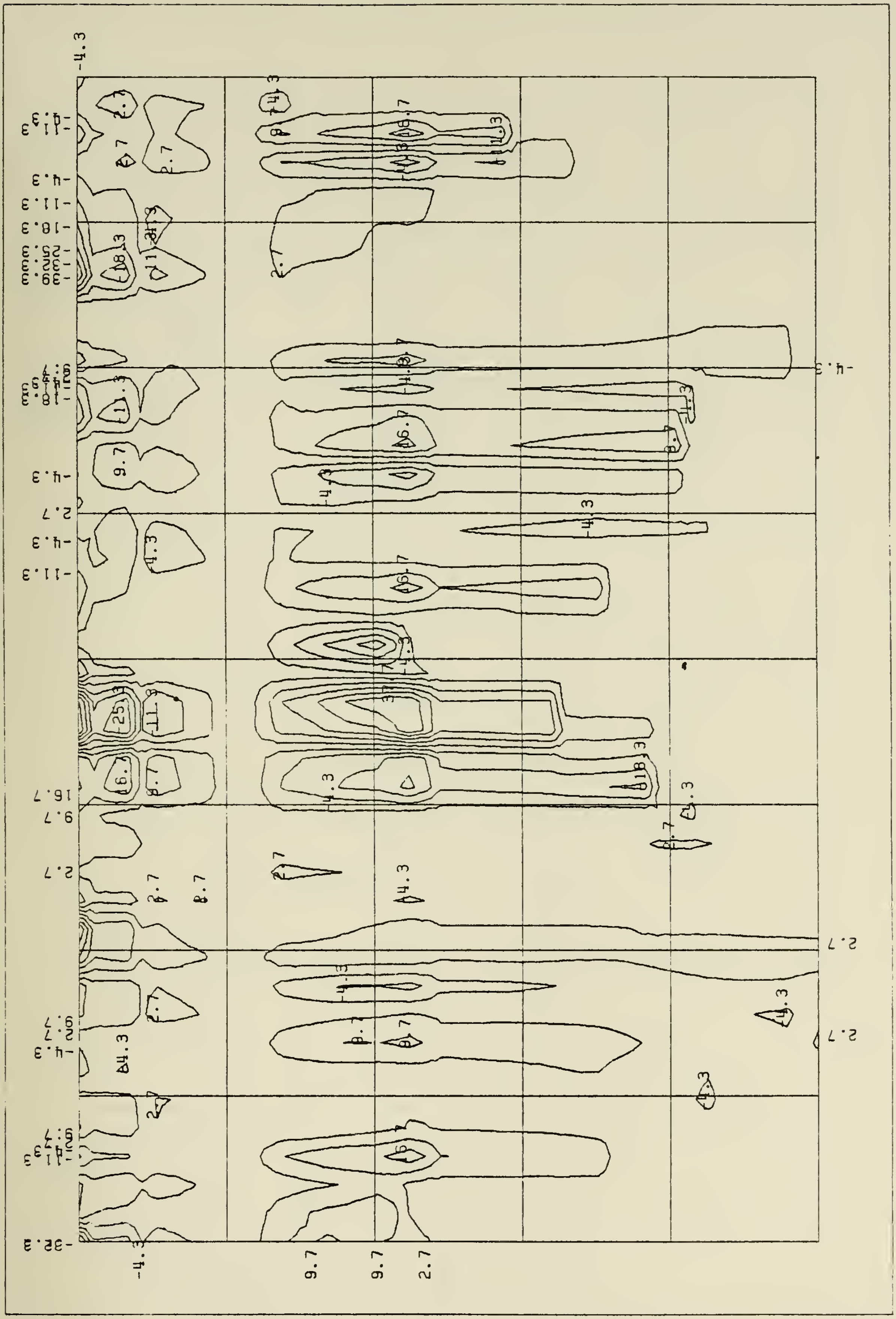
16° HEAT TRANSPORT



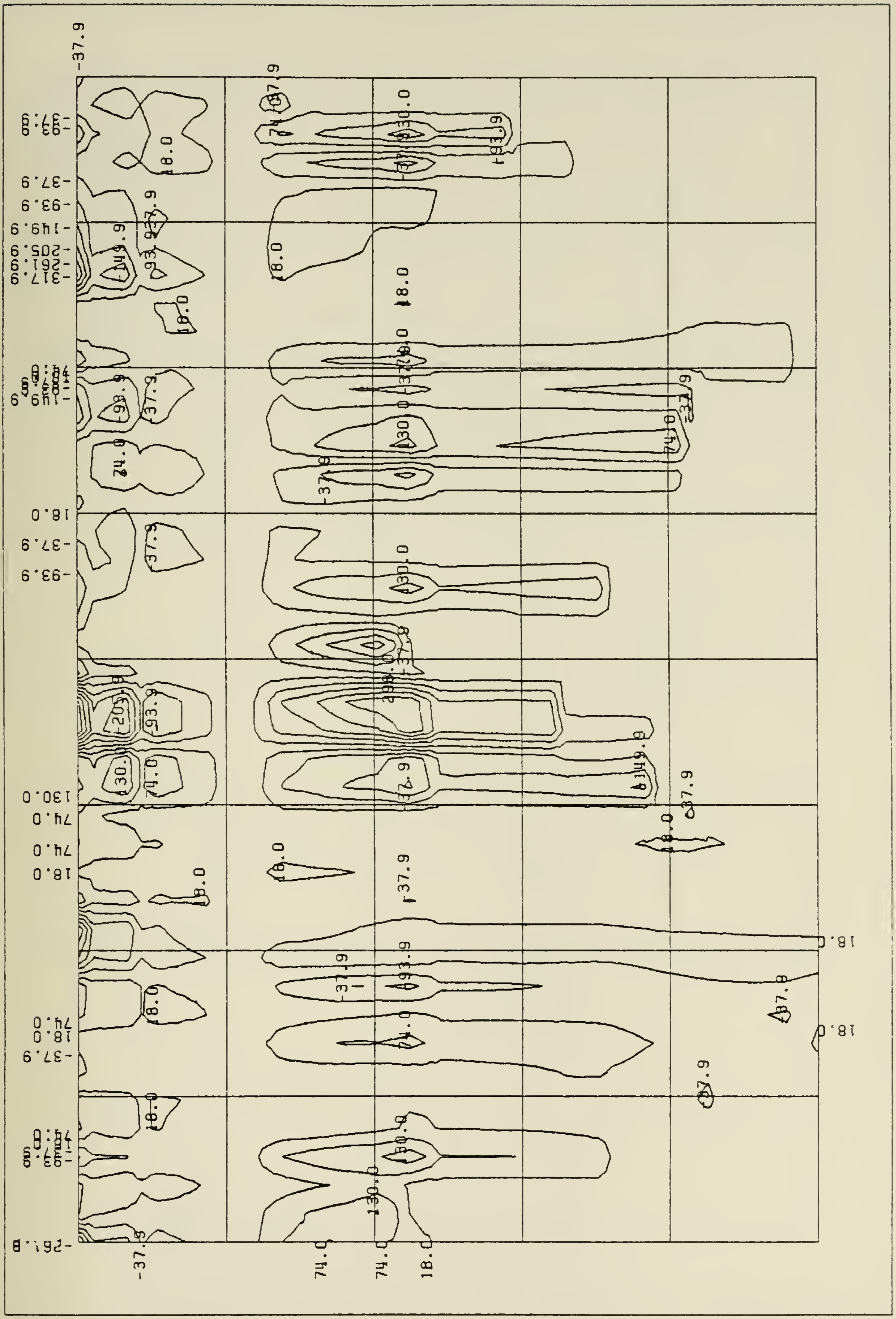
24°S VELOCITY



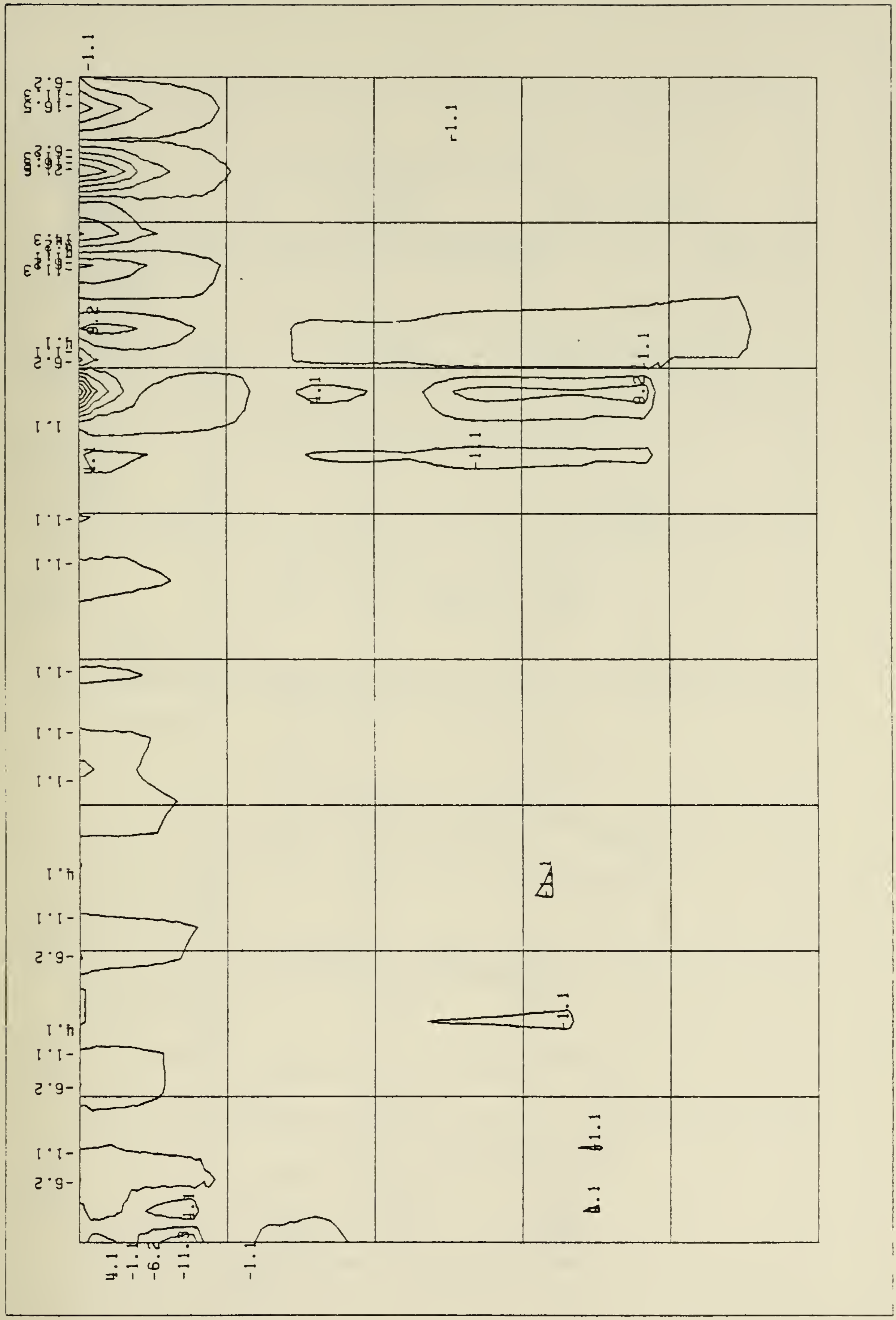
24° MASS TRANSPORT



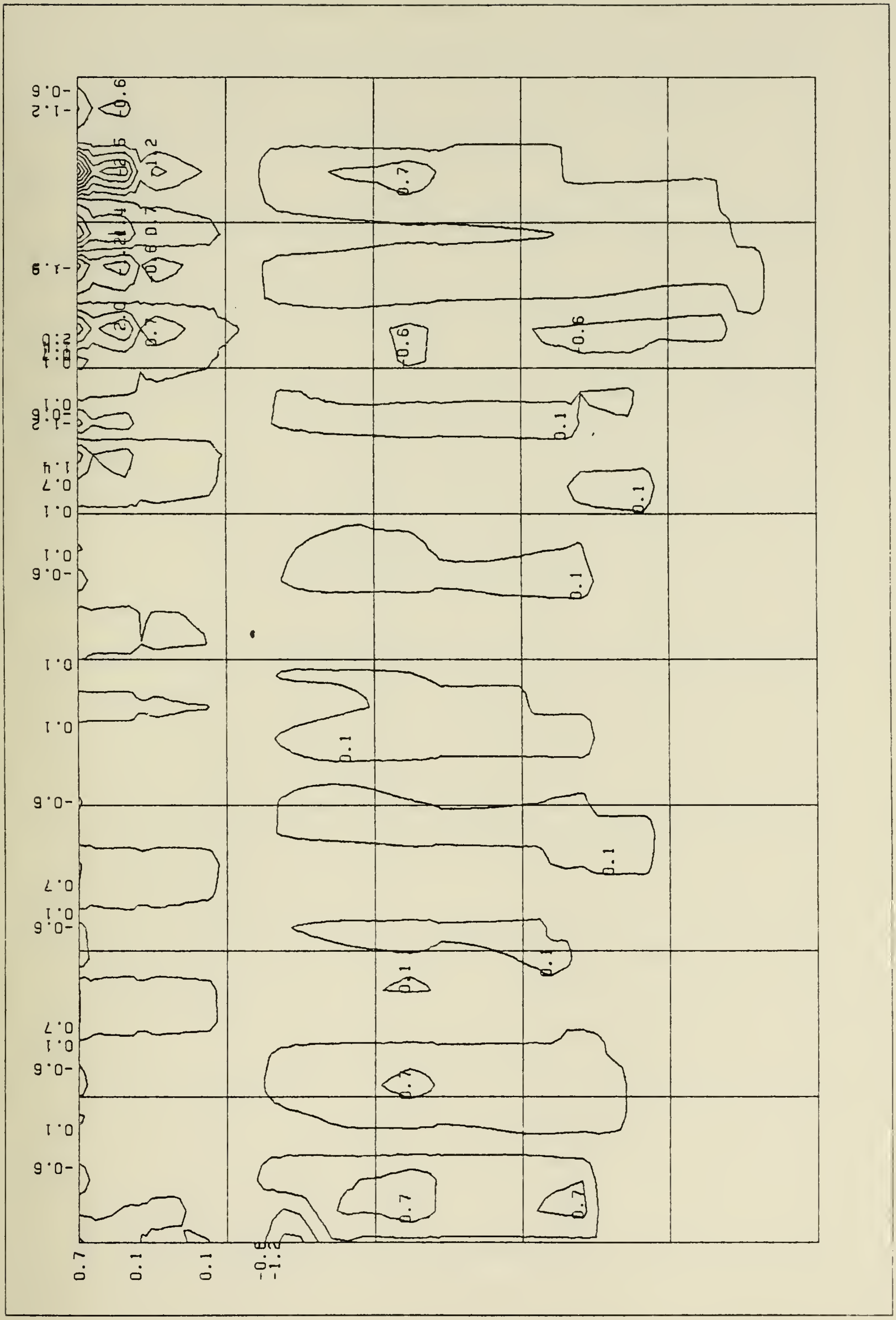
24°S SALT TRANSPORT



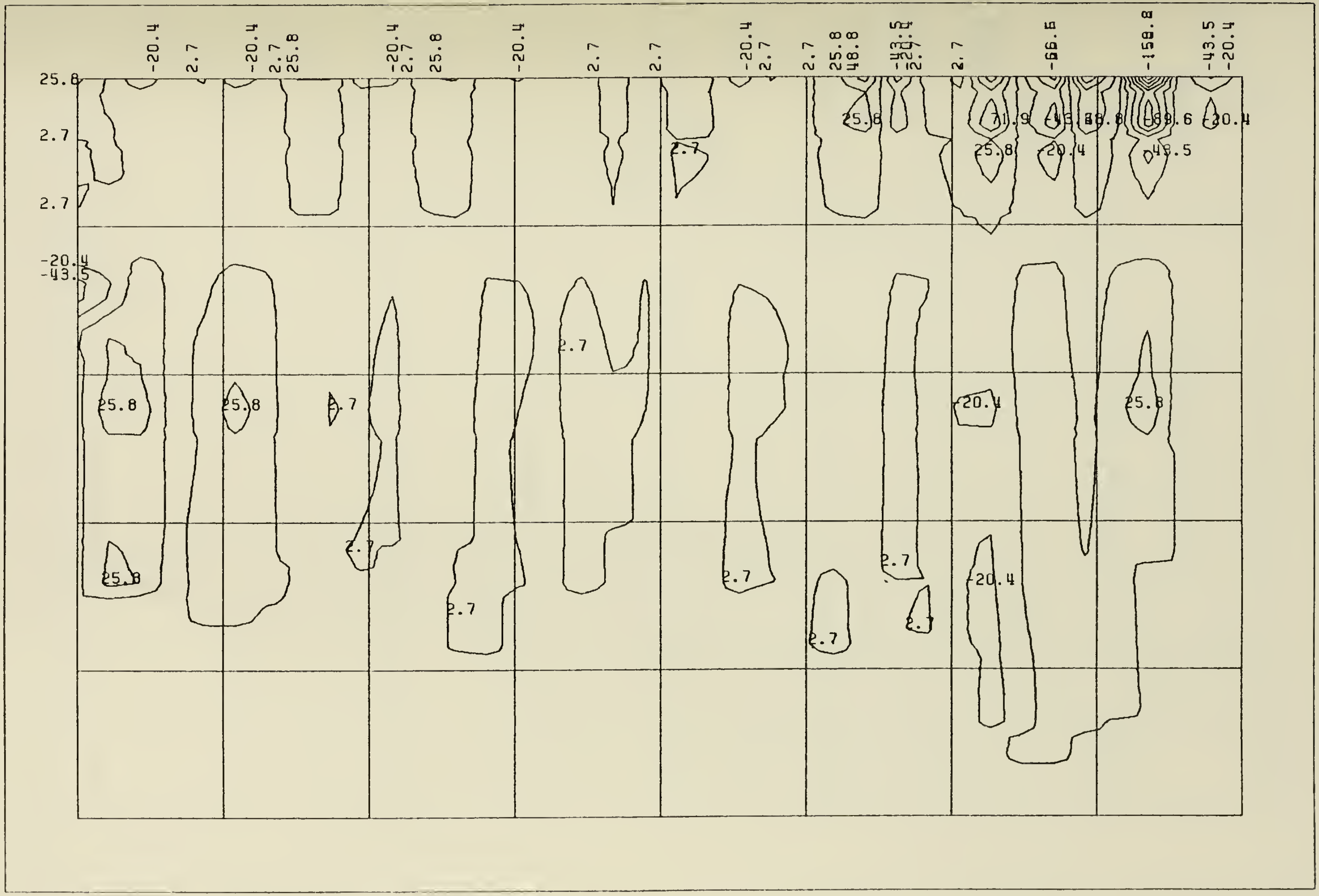
24° HEAT TRANSPORT



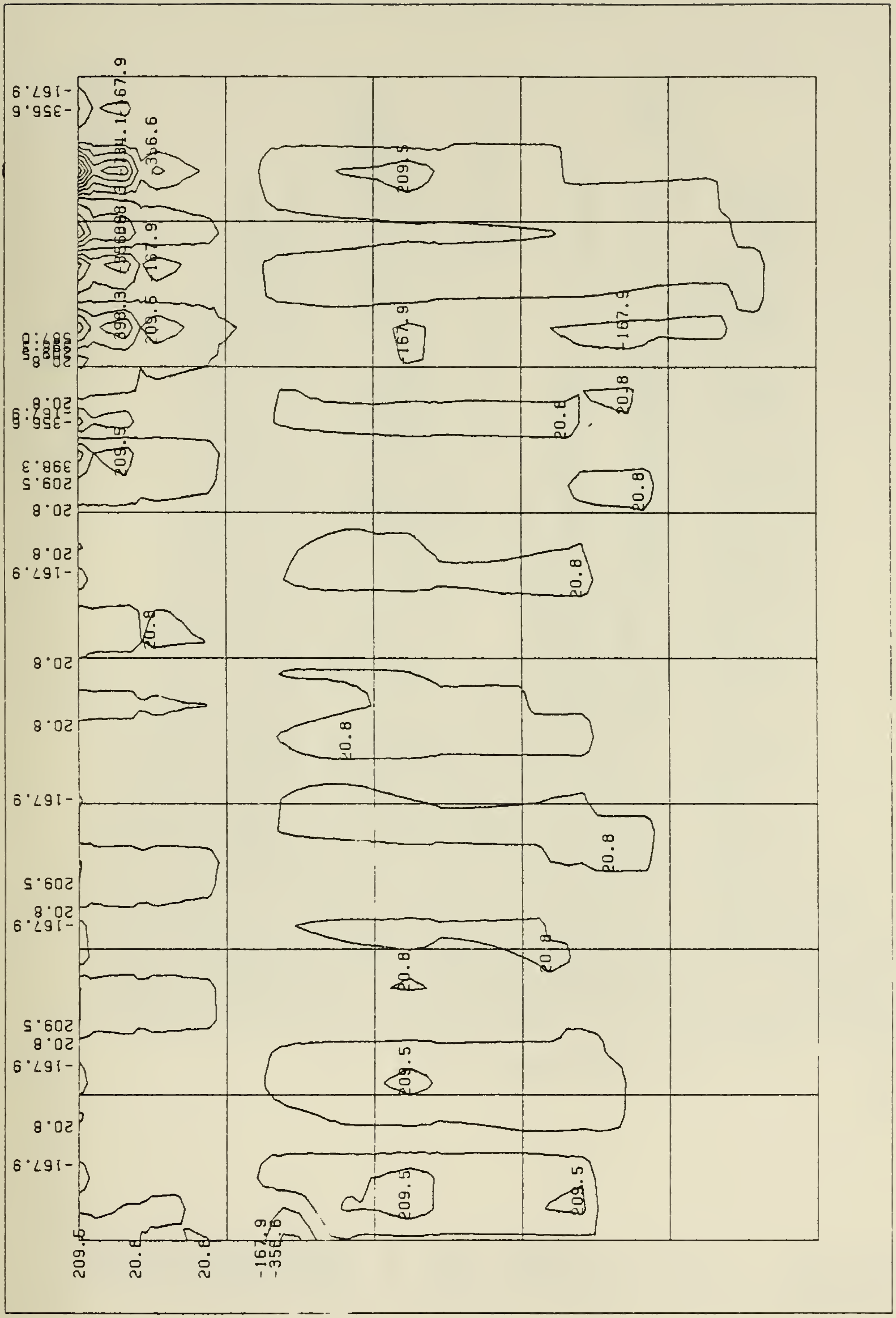
32°S VELOCITY



32° MASS TRANSPORT



32°S SALT TRANSPORT



32° HEAT TRANSPORT

APPENDIX C: COMPUTER PROGRAM

```
FORTRAN IV G LEVEL  21              MAIN              DATE = 78326          15/02/25

0001            REAL *8 ITL(12),INFO(30,8)
0002            DIMENSION SQUARE(60)
0003            DIMENSION Z(48),VEL(48),R(4)
0004            DIMENSION IT(50),IS(50),IC(50)
0005            DIMENSION D(50),T(50),S(50),C2(50),ADD(48),BDD(48)
0006            DIMENSION SD(48),ST(48),SS(48),SCT(48),SV(48),SVA(48)
0007            DIMENSION SGP(48),DH(48),BDH(48),DD(60,48),SLEV(60),BSVA(48)
0008            DIMENSION NPA(60),NPB(60),NO(60),NSTA(60,3),ALT(60),ALM(60)
0009            DIMENSION ALN(60),ANM(60),IDATE(60,3),DHT(60,48),ADH(48)
0010            DIMENSION XDENS(48,60),XSAL(48,60),XTEMP(48,60),YDE(48,60)
0011            DIMENSION YTT(48,60),YSL(48,60),TEMSUM(48),XMSUM(48),SSUM(48)
0012          5 FORMAT(4F7.0)
0013          6 FORMAT(15X,'VELOCITIES COMPUTED ARE RELATIVE TO ',F5.0,' METERS')
0014          7 FORMAT(1H1,'VELOCITIES BETWEEN STATION ',3A4,' LATITUDE ',I2,F5.1,
               1'S LONGITUDE ',I3,F5.1,'W  DATE ',3A4/24X,'AND ',3A4,' LATITUDE ',
               2I2,F5.1,'S LONGITUDE ',I3,F5.1,'W  DATE ',3A4//)
0015          8 FORMAT (1H1,'STATION,',3A4,' LATITUDE ',I2,F5.1,'S LONGITUDE ',
               1I3,F5.1,'W  DATE ',3A4/5X,' TO,',3A4,' LATITUDE ',I2,F5.1,
               2'S LONGITUDE ',I3,F5.1,'W  DATE ',3A4//)
0016          9 FORMAT(8(1X,2I2,F5.0))
0017         10 FORMAT(1H1,'STATION ',3A4,' LATITUDE = ',I2,F5.1,'S LONGITUDE =',
               1I4,F5.1,'W  DATE ',3A4//)
0018         12 FORMAT(10X,'* INDICATES ADJUSTED VALUE')
0019         13 FORMAT(I4,3A4,F3.0,2F5.1,F4.1,3A4)
0020         15 FORMAT(F10.3,F9.2,A1,F10.3,A1,F8.2,A1,8X,4A8)
0021         16 FORMAT(10X,'DEPTH  TEMPERATURE  SALINITY  SIGMA-T  OXYGEN'//)
0022         17 FORMAT(20X,'OBSERVED VALUES'//)
0023         18 FORMAT(//20X,'INTERPOLATED VALUES'//)
0024         19 FORMAT(10X,'DEPTH  TEMPERATURE  SALINITY  SIGMA-T   SPEC VOL  SPEC
               1 V ANOM  MEAN SVA   DELTA D   DYNAMIC HEIGHT'//)
0025         20 FORMAT(10X,F5.0,F10.2,F12.3,F9.3,F11.4,F13.6,23X,F12.5/70X,F11.6,F
               111.5)
0026         21 FORMAT(10X,F5.0,F10.2,A1,F11.3,A1,F8.3,F9.2,A1,4X,4A8/)
0027            DATA SD/0.,150.,300.,450.,500.,550.,660.,770.,880.,990.,1100.,
               11210.,1300.,1430.,1540.,1650.,1760.,1870.,1980.,2090.,2200.,
               22310.,2420.,2530.,2640.,2750.,2860.,2970.,3080.,3190.,3300.,
               33410.,3520.,3630.,3740.,3850.,3960.,4070.,4180.,4290.,4400.,
               44510.,4620.,4730.,4840.,4950.,5060.,5170./
0028            DO 2000 I=1,48
0029            XMSUM(I)=0.
0030            TEMSUM(I)=0.
0031            SSUM(I)=0.
0032       2000 CONTINUE
0033            DO 4 I=1,48
0034          4 Z(I)=-SD(I)
```

```
C
C     MAX NUMBER OF STANDARD DEPTHS IS 48
          NSD=48
C     READ THE NO. OF GEOSTROPHIC CURRENTS AND TRANSPORTS TO BE CALCULATED
C
          READ (5,13) NGC
C
C
C         READ IN THE NUMBER OF SQUARES CORRESPONDING TO THE AREA
C         BELOW THE LAST COMPUTED GEOSTROPHIC VELOCITY
C
C
          READ(5,50)(SQUARE(I),I=1,NGC)
       50 FORMAT(16F5.1)
          IF(NGC.EQ.0) GO TO 410
          READ(5,5)(R(I),I=1,4)
          READ (5,9) (NPA(I),NPB(I),SLEV(I),I=1,NGC)
      410 NPA(NGC+1)=0
          DO 41 L=1,60
C
C               READ HEADING CARD, CHECK FOR  END OF DATA, THEN
C               READ NOV DATA CARDS.
C
          READ (1,13,END=32) NOV,(NSTA(L,K),K=1,3),ALT(L),ALM(L),ALN(L),
         1ANM(L),(IDATE(L,K),K=1,3)
          IF (NOV) 32,32,24
       24 DO 25 I=1,NOV
          READ (1,15) D(I),T(I),IT(I),S(I),IS(I),O2(I),IO(I),
         1(INFO(I,J),J=1,4)
C
C               SGTSVA IS SUBROUTINE TO COMPUTE SIGMA-T, SPECIFIC VOLUME
C               AND SPECIFIC VOLUME ANOMALY.
C
       25 CALL SGTSVA (T(I),S(I),D(I),SGP(I),SVNO,SVNO)
C
C               LGTP IS SUBROUTINE TO COMPUTE INTERPOLATED VALUES
C
          CALL LGTP(NOV,D,T,NSD,SD,ST,NA)
          CALL LGTP(NOV,D,S,NSD,SD,SS,NB)
          NO(L)=NA
          DO 27 I=1,NA
          CALL SGTSVA (ST(I),SS(I),SD(I),SGT(I),SV(I),SVA(I))
       27 CONTINUE
          DO 2500 I=1,NA
          XDENS(I,L)=1./SV(I)
          XTEMP(I,L)=ST(I)+273.15
          XSAL(I,L)=SS(I)
     2500 CONTINUE
          II=NA-1
          DO 2510 I=1,II
          YDE(I,L)=(XDENS(I,L)+XDENS(I+1,L))*.5
```

```
      YTT(I,L)=(XTEMP(I,L)+XTEMP(I+1,L))*.5
      YSL(I,L)=(XSAL(I,L)+XSAL(I+1,L))*.5
 2510 CONTINUE
      NLT=ALT(L)
      NLN=ALN(L)
      WRITE (6,10) (NSTA(L,K),K=1,3),NLT,ALM(L),NLN,ANM(L),
     1(IDATE(L,K),K=1,3)
      WRITE(6,17)
      WRITE (6,16)
      DO 29 I=1,NCV
   29 WRITE (8,21) D(I),T(I),IT(I),S(I),IS(I),SGP(I),C2(I),IO(I),
     1(INFC(I,J),J=1,4)
      WRITE(8,12)
      WRITE(6,18)
      WRITE(8,19)
      NA=NA-1
      DH(1)=0.
      DO 30 I=1,NA
      BSVA(I)=(SVA(I)+SVA(I+1))*.5
      DD(L,I)=BSVA(I)*(SD(I+1)-SD(I))
   30 DH(I+1)=DH(I)+DD(L,I)
      DO 31 I=1,NA
      DHT(L,I)=DH(I)
   31 WRITE (6,20) SD(I),ST(I),SS(I),SGT(I),SV(I),SVA(I),DH(I),
     1BSVA(I),DD(L,I)
      I=NA+1
      DHT(L,I)=DH(I)
      WRITE (8,20) SD(I),ST(I),SS(I),SGT(I),SV(I),SVA(I),DH(I)
   41 CONTINUE
   32 IF(NGC.EQ.0) GO TO 33
      DO 42 L=1,60
      IF (NPA(L).EQ.0) GO TO 3999
      BASE=SLEV(L)
      N1=NPA(L)
      N2=NPB(L)
      NU1=NO(N1)
      NU2=NO(N2)
      DO 43 I=1,NU1
      ADD(I)=DD(N1,I)
   43 ADH(I)=DHT(N1,I)
      DO 44 I=1,NU2
      BDD(I)=DD(N2,I)
   44 BDH(I)=DHT(N2,I)
      NLT=ALT(N1)
      NLN=ALN(N1)
      MLT=ALT(N2)
      MLN=ALN(N2)
      WRITE (6,8) (NSTA(N1,K),K=1,3),NLT,ALM(N1),NLN,ANM(N1),
     1(IDATE(N1,K),K=1,3),(NSTA(N2,K),K=1,3),MLT,ALM(N2),MLN,
     2ANM(N2),(IDATE(N2,K),K=1,3)
```

```
      ALAT=ALT(N1)+ALM(N1)/60.
      BLAT=ALT(N2)+ALM(N2)/60.
      IF (ALN(N1) .LT. 0.)GO TO 500
      ALON=ALN(N1)+ANM(N1)/60.
      GO TO 502
  500 ALON=ALN(N1)-ANM(N1)/60
  502 IF (ALN(N2) .LT. 0.)GO TO 501
      BLON=ALN(N2)+ANM(N2)/60.
      GO TO 503
  501 BLON=ALN(N2)-ANM(N2)/60
  503 CALL DSTSTA (ALAT,ALON,BLAT,BLON,X2,DIST)
      CALL GEOCUR (NU1,ADH,NU2,BDH,SD,BASE,X2,VEL,NNN,DIST,YUE,YTT,YSL,
     1XMSUM,TEMSUM,SSUM,L,SQUARE,NCC)
      WRITE (8,7) (NSTA(N1,K),K=1,3),NLT,ALM(N1),NLN,ANM(N1),
     1(IDATE(N1,K),K=1,3),(NSTA(N2,K),K=1,3),MLT,ALM(N2),MLN,
     2ANM(N2),(IDATE(N2,K),K=1,3)
      XS=(R(1)-R(2))/60.
      YS=(R(3)-R(4))/60.
      WRITE(8,100) XS,YS
  100 FORMAT( 15X,'X-SCALE:  "*"=',F4.1,' CM/SEC'//
     1        15X,'Y-SCALE:  "*"=',F5.2,' METERS'//)
      WRITE(8,6) BASE
   42 CONTINUE
 3999 TSSUM=0.0
      THSUM=0.0
      TMSUM=0.0
      WRITE (6,6002)
 6002 FORMAT('1',20X,'DEPTH',10X,'TOTAL MASS',10X,'TOTAL SALT',10X,'TOTA
     1L HEAT'/35X,'TRANSPORT',11X,'TRANSPORT',11X,'TRANSPORT')
      DO 5000 J=1,47
      TMSUM=TMSUM+XMSUM(J)
      THSUM=THSUM+TEMSUM(J)
      TSSUM=TSSUM+SSUM(J)
      WRITE (6,6003) J,SD(J),XMSUM(J),SSUM(J),TEMSUM(J)
 6003 FORMAT ('0',10X,I4,6X,F5.0/29X,E16.6,4X,E16.6,4X,E16.6)
 5000 CONTINUE
      IX=48
      WRITE (6,6003) IX,SD(IX)
      WRITE (6,6004)
 6004 FORMAT (' ',37X,'--------',12X,'--------',12X,'--------')
      WRITE(6,7000)
 7000 FORMAT('0',16X,'SUBTOTAL')
      WRITE (6,6001) TMSUM,TSSUM,THSUM
 6001 FORMAT ('+',29X,E16.6,4X,E16.6,4X,E16.6)
      WRITE(6,7001) XMSUM(48),SSUM(48),TEMSUM(48)
 7001 FORMAT (///14X,'BOTTOM AREA',5X,E16.6,4X,E16.6,4X,E16.6/13X,
     *'CONTRIBUTION')
```

```
      TMSUM=TMSUM+XMSUM(48)
      TSSUM=TSSUM+SSUM(48)
      THSUM=THSUM+TEMSUM(48)
      WRITE(6,6004)
      WRITE(6,7002)
 7002 FORMAT('0',13X,'GRAND TOTAL')
      WRITE (6,6001) TMSUM,TSSUM,THSUM
   33 STOP
      END
```

```
      SUBROUTINE LGTP(N,D,V,M,SD,CV,NN)
      DIMENSION D(50),V(50),CV(48),SD(48)
      JJJ=0
  111 DO 188 J=1,M
  112 DO 186 I=1,N
      IF(SD(J)-D(N))113,115,190
  115 CV(J)=V(N)
      JJJ=JJJ+1
      GO TO 190
  113 IF(SD(J)-D(I))114,114,116
  114 CV(J)=V(I)
      GO TO 170
  116 IF(SD(J)-D(I+1))120,118,186
  118 CV(J)=V(I+1)
      GO TO 170
  120 IF(((D(1).LT.SD(J)).AND.(SD(J).LT.D(2))).OR.
     $   ((D(N-1).LT.SD(J)).AND.(SD(J).LT.D(N)))) GO TO 134
      XA=(SD(J)-D(I))*(SD(J)-D(I+1))*V(I-1)/
     1((D(I-1)-D(I))*(D(I-1)-D(I+1)))
      XB=(SD(J)-D(I-1))*(SD(J)-D(I+1))*V(I)/
     1((D(I)-D(I-1))*(D(I)-D(I+1)))
      XC=(SD(J)-D(I-1))*(SD(J)-D(I))*V(I+1)/
     1((D(I+1)-D(I-1))*(D(I+1)-D(I)))
      ANSU=XA+XB+XC
      YA=(SD(J)-D(I+1))*(SD(J)-D(I+2))*V(I)/
     1((D(I)-D(I+1))*(D(I)-D(I+2)))
      YB=(SD(J)-D(I))*(SD(J)-D(I+2))*V(I+1)/
     1((D(I+1)-D(I))*(D(I+1)-D(I+2)))
      YC=(SD(J)-D(I))*(SD(J)-D(I+1))*V(I+2)/
     1((D(I+2)-D(I))*(D(I+2)-D(I+1)))
      ANSD=YA+YB+YC
      CV(J)=(ANSU+ANSD)/2.
      GO TO 170
  134 ZA=(SD(J)-D(I+1))*V(I)/(D(I)-D(I+1))
      ZB=(SD(J)-D(I))*V(I+1)/(D(I+1)-D(I))
      ANSL=ZA+ZB
      CV(J)=ANSL
      GO TO 170
  186 CONTINUE
  170 JJJ=JJJ+1
  188 CONTINUE
  190 NN=JJJ
      RETURN
      END
```

```
      SUBROUTINE DSTSTA (SATI,ONGI,SATII,ONGII,X2,DIST)
      IMPLICIT REAL*4 (K)
      REAL*8 A,E
      DATA A/111132.09/,B/566.05/,C/1.20/,D/.002/
      DATA E/111415.13/,F/94.55/,G/.012/
   10 FORMAT (10X,'MEAN LATITUDE = ',F6.2/15X,'DISTANCE = ',F6.2,
     1' KILOMETERS'/)
      CON=2*3.1416/360
      AATI=SATI*CON
      AATII=SATII*CON
      $MERI=A-B*COS(2*AATI)+C*COS(4*AATI)-D*COS(6*AATI)
      PARI=E*COS(AATI)-F*COS(3*AATI)+G*COS(5*AATI)
      $MERII=A-B*COS(2*AATII)+C*COS(4*AATII)-D*COS(6*AATII)
      PARII=E*COS(AATII)-F*COS(3*AATII)+G*COS(5*AATII)
      ALLAT=($MERI+$MERII)/2
      ALLON=(PARI+PARII)/2
      DLAT=SATI-SATII
      DLON=ONGI-ONGII
      KLAT=DLAT*ALLAT/1000
      KLONG=DLON*ALLON/1000
      KDIX=SQRT(KLAT**2+KLONG**2)
      DIST=KDIX
      W2=1.458E-4
      PSI=(SATI+SATII)*0.5
      PSJ=(2.*3.14159/360.)*PSI
      SPSI=SIN(PSJ)
      IF(SPSI.LT.0.1) SPSI=0.1
      X2=1./(W2*SPSI*KDIX)
      WRITE(6,10) PSI,KDIX
      RETURN
      END
```

```
      SUBROUTINE SGTSVA (T,S,D,SGT,SV,SVA)
      ST=-(((T-3.98)**2)/503.57)*((T+283.)/(T+67.26))
      SO=-0.093+0.8149*S-.000482*S**2+6.8E-6*S**3
      AT=T*(4.7867-.098185*T+.0010843*T**2)*1.E-3
      BT=T*(18.030-.8164*T+.01667*T**2)*1.E-6
      SGT=ST+(SO+.1324)*(1.-AT+BT*(SO-.1324))
      AFST=1./(1.+SGT*1.E-3)
      A=D*AFST*1.E-9
      B=4886./(1.+1.83E-5*D)
      C=227.+28.33*T-.551*T**2+.004*T**3
      E=D*1.E-4
      G=(SO-28.)/10.
      H=147.3-2.72*T+.04*T**2
      U=105.5+9.5*T-.158*T**2
      V=1.5*D**2*T*1.E-8
      W=32.4-.87*T+.02*T**2
      X=4.5-.1*T
      Y=1.8-.06*T
      SV=AFST-A*(B-C+E*U-V-G*(H-E*W)+G**2*(X-E*Y))
      AZ=.972643
      YA=-227.+.01055*D
      YB=.01296*(147.3-.00324*D)
      YC=16.E-7*(4.5-D*.00018)
      AP=AZ-D*AZ*(B+YA-YB+YC)*1.E-9
      SVA=SV-AP
      RETURN
      END
```

```
0001        SUBROUTINE GEOCUP (NA,ADH,NB,BDH,SD,BASE,X2,VEL,NNN,DIST,
           1YDE,YTT,YSL,XMSUM,TEMSUM,SSUM,L,SQUARE,NGC)
0002        DIMENSION X(48),Y(60),XL(48),YL(60),FL(48,60),WK(165)
0003        REAL *8 TITLE(12),TITL1(12),TITL2(12),TITL3(12)
0004        DIMENSION ABVEL(48,60),CL(20),BMASST(48,60),BSALTT(48,60),
           1BHEATT(48,60)
0005        LOGICAL*1 LTG(3)/.TRUE.,.TRUE.,.TRUE./
0006        DIMENSION SQUARE(60)
0007        DIMENSION AMASST(48),ASALTT(48),AHEATT(48),XMSUM(48),TEMSUM(48),
           1SSUM(48),YDE(48,60),YTT(48,60),YSL(48,60),AVDENS(48),AVTEMP(48),
           2AVSAL(48)
0008        DIMENSION ADH(48),BDH(48),SD(48),RVEL(48),VEL(48),AMB(48),AVT(48)
0009     10 FORMAT (13X,'DEPTH      DYN HT    DYN HT      DIFF HT    REL VEL    ABS V
           1EL      AVERAGE      AVERAGE ABS      AVERAGE        WATER MASS'/15X,'M
           2   STA A      STA B         B-A       CM/SEC      CM/SEC         DENSITY       TEM
           3PERATURE      SALINITY      TYPE'/)
0010     11 FORMAT (12X,F5.0,2X,3(F9.5,1X),2(F6.2,2X)/67X,F12.5,3X,F10.2,4X,F1
           10.3)
0011     12 FORMAT ('***** LEVEL OF NO MOTION MUST BE EQUAL TO A STANDARD DEPT
           1H ******')
0012     14 FORMAT(' ',10X,'TOTAL VOLUME TRANSPORT IS COMPUTED BY SUMMING INCR
           1EMENTAL TRANSPORTS ABOVE LEVEL OF NO MOTION:'//5X,'TOTAL TRANSPORT
           2 PERPENDICULAR TO THE PLANE OF THE STATIONS IS ',F7.3,' SVERDRUPS
           3RELATIVE TO ',F5.0,' METERS')
0013     15 FORMAT(//'  * VALUES IN THIS COLUMN REPRESENT TRANSPORTS IN LAYER
           1INCREMENTS'//)
0014     16 FORMAT (//13X,'DEPTH',10X,'ABS VOL',8X,'ABS MASS',7X,'ABS SALT',7X
           1,'ABS HEAT'/15X,'M',12X,'TRANSPORT',6X,'TRANSPORT',6X,'TRANSPORT',
           26X,'TRANSPORT',8X,'MASS',11X,'SALT',11X,'HEAT'/)
0015     17 FORMAT (12X,F5.0/22X,7(F15.5))
0016     18 FORMAT ('0',32X,'*',14X,'*',14X,'*',14X,'*',20X,'CUMULATIVE TOTALS
           1')
0017        IF(L .GT. 1) GO TO 50
0018        YY=0.
0019        DO 1 J=1,47
0020      1 X(J)=(SD(J)+SD(J+1))/2.
0021        XL(1)=50.
0022        DO 3 I=1,47
0023      3 XL(I+1)=(I*110.)+50.
0024        DO 2001 I=1,48
0025        DO 2001 J=1,60
```

```
      BMASST(I,J)=0.
      BSALTT(I,J)=0.
      BHEATT(I,J)=0.
 2001 ABVEL(I,J)=0.
      READ (5,2002) TITLE,TITL1,TITL2,TITL3
 2002 FORMAT (6A8)
      TETMAS=0.0
      TCRMAS=0.0
      TINMAS=0.0
      TCNMAS=0.0
      TDFMAS=0.0
      TSBMAS=0.0
      TSFMAS=0.0
      TUNMAS=0.0
      TBTSLT=0.0
      TCRSLT=0.0
      TINSLT=0.0
      TCNSLT=0.0
      TDFSLT=0.0
      TSBSLT=0.0
      TSFSLT=0.0
      TUNSLT=0.0
      TBTHT =0.0
      TCRHT =0.0
      TINHT =0.0
      TCNHT =0.0
      TDPHT =0.0
      TSBHT =0.0
      TSFHT =0.0
      TUNHT =0.0
   50 CONTINUE
      BCTMAS   =0.0
      CIRMAS   =0.0
      AINMAS   =0.0
      CENMAS   =0.0
      DEPMAS   =0.0
      SLEMAS   =0.0
      SFCMAS   =0.0
      UNKMAS   =0.0
```

```
      BCTSLT=0.0
      CIRSLT=0.0
      AINSLT=0.0
      CENSLT=0.0
      DEPSLT=0.0
      SLESLT=0.0
      SFCSLT=0.0
      LNKSLT=0.0
      BCTHT=0.0
      CIRHT=0.0
      AINHT=0.0
      CENHT=0.0
      DEPHT=0.0
      SLBHT=0.0
      SFCHT=0.0
      LNKHT=0.0
      IF(NA.LE.NB) GO TO 51
      N=NB
      GO TO 52
   51 N=NA
   52 DO 53 I=1,N
      AMB(I)=BDH(I)-ADH(I)
   53 RVEL(I)=AMB(I)*X2
      DO 54 I=1,46
      IF(BASE.EQ.SD(I))GO TO 55
   54 CONTINUE
      WRITE (6,12)
      GO TO 70
   55 NM=I
      IF(NM.GT.N) NM=N
      BASE=SD(NM)
      DO 56 I=1,N
      VEL(I)=RVEL(NM)-RVEL(I)
   56 ABVEL(I,L) =VEL(I)
```

```
0092              ABSVEL=VEL(N)
0093              STMASS=0.0
0094              STSALT=0.0
0095              STHEAT=0.0
0096              WRITE(6,10)
0097              DO 600 I=2,N
0098              J=I-1
0099              AVDENS(J)=(YDE(J,L)+YDE(J,L+1))*.5
0100              AVSAL(J)=(YSL(J,L)+YSL(J,L+1))*.5
0101              AVTEMP(J)=(YTT(J,L)+YTT(J,L+1))*.5
0102              AVEL=(VEL(I)+VEL(J))*0.005
0103              AVT(J)=AVEL*DIST*(SD(I)-SD(J))*1.0E-03
0104              AMASST(J)=AVT(J)*AVDENS(J)
0105              BMASST(J,L)=AVT(J)*AVDENS(J)
0106              ASALTT(J)=AMASST(J)*AVSAL(J)
0107              BSALTT(J,L)=AMASST(J)*AVSAL(J)
0108              AHEATT(J)=AMASST(J)*AVTEMP(J)
0109              BHEATT(J,L)=AMASST(J)*AVTEMP(J)
0110              XMSUM(J)=XMSUM(J)+AMASST(J)
0111              SSUM(J)=SSUM(J)+ASALTT(J)
0112              TEMSUM(J)=TEMSUM(J)+AHEATT(J)
0113              STMASS=STMASS+AMASST(J)
0114              STSALT=STSALT+ASALTT(J)
0115              STHEAT=STHEAT+AHEATT(J)
0116              IF (I .LT. N) GO TO 141
0117              XFAC=250000.
0118              AVT(48)=ABSVEL*SQUARE(L)*XFAC/200.0E06
0119              AMASST(48)=AVT(48)*AVDENS(N-1)
0120              ASALTT(48)=AMASST(48)*AVSAL(N-1)
0121              AHEATT(48)=AMASST(48)*AVTEMP(N-1)
0122              XMSUM(48)=XMSUM(48)+AMASST(48)
0123              SSUM(48)=SSUM(48)+ASALTT(48)
0124              TEMSUM(48)=TEMSUM(48)+AHEATT(48)
0125              STMASS=STMASS+AMASST(48)
0126              STSALT=STSALT+ASALTT(48)
0127              STHEAT=STHEAT+AHEATT(48)
0128          141 IF((AVTEMP(J) .LE. 273.0) .AND. ((34.65 .LE. AVSAL(J)) .AND.
                 1(AVSAL(J) .LE. 34.67))) GO TO 4000
0129              IF(((273.7 .LE. AVTEMP(J)) .AND. (AVTEMP(J) .LE. 277.4)) .AND.
```

```
      1((34.700 .LE.AVSAL(J)) .AND. (AVSAL(J).LE.34.973))) GO TO 4004
       IF(((275.87.LE. AVTEMP(J)) .AND. (AVTEMP(J) .LE. 280.0)) .AND.
      1((33.80 .LE. AVSAL(J)) .AND. (AVSAL(J) .LE. 34.709))) GO TO 4002
       IF(((276.0 .LE. AVTEMP(J)) .AND. (AVTEMP(J) .LE. 291.0)) .AND.
      1((34.45 .LE. AVSAL(J)) .AND. (AVSAL(J) .LE.36.28))) GO TO 4003
       IF(((273.0 .LE. AVTEMP(J)) .AND. (AVTEMP(J) .LE. 275.5)) .AND.
      1((34.68 .LE. AVSAL(J)) .AND. (AVSAL(J) .LE. 34.8))) GO TO 4001
       IF(((280.0 .LE. AVTEMP(J)) .AND. (AVTEMP(J) .LE. 282.0)) .AND.
      1((34.10 .LE. AVSAL(J)) .AND. (AVSAL(J) .LE. 34.68))) GO TO 4005
       IF(AVTEMP(J) .GE. 291.0) GO TO 4006
       IF(((272.0 .LE. AVTEMP(J)) .AND. (AVTEMP(J) .LE. 300.0)) .AND.
      1((32.00 .LE. AVSAL(J)) .AND. (AVSAL(J) .LE. 37.00))) GO TO 4007
 4000 WRITE (6,11) SD(J),ADH(J),BDH(J),AMB(J),RVEL(J),VEL(J),AVDENS(J),
      1AVTEMP(J),AVSAL(J)
       WRITE (6,30)
   30 FORMAT ('+',109X,'A.A. BOTTOM')
       BOTMAS    =BOTMAS    +AMASST(J)
       BOTHT     =BOTHT     +AHEATT(J)
       BOTSLT    =BOTSLT    +ASALTT(J)
       TBTMAS=TBTMAS+AMASST(J)
       TBTHT=TBTHT+AHEATT(J)
       TBTSLT=TBTSLT+ASALTT(J)
       IF (I .LT. N) GO TO 39
       BOTMAS    =BOTMAS    +AMASST(48)
       BOTHT     =BOTHT     +AHEATT(48)
       BOTSLT    =BOTSLT    +ASALTT(48)
       TBTMAS=TBTMAS+AMASST(48)
       TBTHT=TBTHT+AHEATT(48)
       TBTSLT=TBTSLT+ASALTT(48)
       GO TO 39
 4001 WRITE (6,11) SD(J),ADH(J),BDH(J),AMB(J),RVEL(J),VEL(J),AVDENS(J),
      1AVTEMP(J),AVSAL(J)
       WRITE (6,31)
   31 FORMAT ('+',109X,'A.A. CIRCUMPOLAR')
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```
      CIRMAS    =CIRMAS    +AMASST(J)
      CIRHT     =CIRHT     +AHEATT(J)
      CIRSLT    =CIRSLT    +ASALTT(J)
      TCRMAS=TCRMAS+AMASST(J)
      TCRHT=TCRHT+AHEATT(J)
      TCRSLT=TCRSLT+ASALTT(J)
      IF (I .LT. N) GO TO 39
      CIRMAS    =CIRMAS    +AMASST(48)
      CIRHT     =CIRHT     +AHEATT(48)
      CIRSLT    =CIRSLT    +ASALTT(48)
      TCRMAS=TCRMAS+AMASST(48)
      TCRHT=TCRHT+AHEATT(48)
      TCRSLT=TCRSLT+ASALTT(48)
      GO TO 39
 4002 WRITE (6,11) SD(J),ADH(J),BDH(J),AMB(J),RVEL(J),VEL(J),AVDENS(J),
     1AVTEMP(J),AVSAL(J)
      WRITE (6,32)
   32 FORMAT ('+',109X,'A.A. INTERMEDIATE')
      AINMAS    =AINMAS    +AMASST(J)
      AINHT     =AINHT     +AHEATT(J)
      AINSLT    =AINSLT    +ASALTT(J)
      TINMAS=TINMAS+AMASST(J)
      TINHT=TINHT+AHEATT(J)
      TINSLT=TINSLT+ASALTT(J)
      IF (I .LT. N) GO TO 39
      AINMAS    =AINMAS    +AMASST(48)
      AINHT     =AINHT     +AHEATT(48)
      AINSLT    =AINSLT    +ASALTT(48)
      TINMAS=TINMAS+AMASST(48)
      TINHT=TINHT+AHEATT(48)
      TINSLT=TINSLT+ASALTT(48)
      GO TO 39
 4003 WRITE (6,11) SD(J),ADH(J),BDH(J),AMB(J),RVEL(J),VEL(J),AVDENS(J),
     1AVTEMP(J),AVSAL(J)
      WRITE (6,33)
   33 FORMAT ('+',109X,'S. ATL. CENTRAL')
      CENMAS    =CENMAS    +AMASST(J)
      CENHT     =CENHT     +AHEATT(J)
      CENSLT    =CENSLT    +ASALTT(J)
```

```
      TCNMAS=TCNMAS+AMASST(J)
      TCNHT=TCNHT+AHEATT(J)
      TCNSLT=TCNSLT+ASALTT(J)
      IF (I .LT. N) GO TO 39
      CENMAS    =CENMAS    +AMASST(48)
      CENHT     =CENHT     +AHEATT(48)
      CENSLT    =CENSLT    +ASALTT(48)
      TCNMAS=TCNMAS+AMASST(48)
      TCNHT=TCNHT+AHEATT(48)
      TCNSLT=TCNSLT+ASALTT(48)
      GO TO 39
 4004 WRITE (6,11) SD(J),ADH(J),BDF(J),AMB(J),RVEL(J),VEL(J),AVDENS(J),
     1AVTEMP(J),AVSAL(J)
      WRITE (6,34)
   34 FORMAT ('+',109X,'DEEP')
      DEPMAS    =DEPMAS    +AMASST(J)
      DEPHT     =DEPHT     +AHEATT(J)
      DEPSLT    =DEPSLT    +ASALTT(J)
      TDPMAS=TDPMAS+AMASST(J)
      TDPHT=TDPHT+AHEATT(J)
      TDPSLT=TDPSLT+ASALTT(J)
      IF (I .LT. N) GO TO 39
      DEPMAS    =DEPMAS    +AMASST(48)
      DEPHT     =DEPHT     +AHEATT(48)
      DEPSLT    =DEPSLT    +ASALTT(48)
      TDPMAS=TDPMAS+AMASST(48)
      TDPHT=TDPHT+AHEATT(48)
      TDPSLT=TDPSLT+ASALTT(48)
      GO TO 39
 4005 WRITE (6,11) SD(J),ADH(J),BDF(J),AMB(J),RVEL(J),VEL(J),AVDENS(J),
     1AVTEMP(J),AVSAL(J)
      WRITE (6,35)
   35 FORMAT ('+',109X,'SUB ANTARCTIC')
      SUBMAS    =SUBMAS    +AMASST(J)
```

```
      SUBHT     =SUBHT     +AHEATT(J)
      SUBSLT    =SUBSLT    +ASALTT(J)
      TSBMAS=TSBMAS+AMASST(J)
      TSBHT=TSBHT+AHEATT(J)
      TSBSLT=TSBSLT+ASALTT(J)
      IF (I .LT. N) GO TO 39
      SUBMAS    =SUBMAS    +AMASST(48)
      SUBHT     =SUBHT     +AHEATT(48)
      SUBSLT    =SUBSLT    +ASALTT(48)
      TSBMAS=TSBMAS+AMASST(48)
      TSBHT=TSBHT+AHEATT(48)
      TSBSLT=TSBSLT+ASALTT(48)
      GO TO 39
 4006 WRITE (6,11) SD(J),ADH(J),BDH(J),AMB(J),RVEL(J),VEL(J),AVDENS(J),
     1AVTEMP(J),AVSAL(J)
      WRITE (6,36)
   36 FORMAT ('+',109X,'SURFACE')
      SFCMAS    =SFCMAS    +AMASST(J)
      SFCHT     =SFCHT     +AHEATT(J)
      SFCSLT    =SFCSLT    +ASALTT(J)
      TSFMAS=TSFMAS+AMASST(J)
      TSFHT=TSFHT+AHEATT(J)
      TSFSLT=TSFSLT+ASALTT(J)
      IF (I .LT. N) GO TO 39
      SFCMAS    =SFCMAS    +AMASST(48)
      SFCHT     =SFCHT     +AHEATT(48)
      SFCSLT    =SFCSLT    +ASALTT(48)
      TSFMAS=TSFMAS+AMASST(48)
      TSFHT=TSFHT+AHEATT(48)
      TSFSLT=TSFSLT+ASALTT(48)
      GO TO 39
 4007 WRITE (6,11) SD(J),ADH(J),BDH(J),AMB(J),RVEL(J),VEL(J),AVDENS(J),
     1AVTEMP(J),AVSAL(J)
      WRITE (6,37)
   37 FORMAT ('+',109X,'UNKNOWN')
      UNKMAS    =UNKMAS    +AMASST(J)
      UNKHT     =UNKHT     +AHEATT(J)
      UNKSLT    =UNKSLT    +ASALTT(J)
      TUNMAS=TUNMAS+AMASST(J)
```

```
      TUNHT=TUNHT+AHEATT(J)
      TUNSLT=TUNSLT+ASALTT(J)
      IF (I .LT. N) GO TO 39
      UNKMAS    =UNKMAS    +AMASST(48)
      UNKHT     =UNKHT     +AHEATT(48)
      UNKSLT    =UNKSLT    +ASALTT(48)
      TUNMAS=TUNMAS+AMASST(48)
      TUNHT=TUNHT+AHEATT(48)
      TUNSLT=TUNSLT+ASALTT(48)
   39 CONTINUE
  600 CONTINUE
      WRITE(6,11) SD(N),ADH(N),BDH(N),AMB(N),RVEL(N),VEL(N)
      NM=NM-1
      VT=0.
      DO 57 I=1,NM
   57 VT=VT+AVT(I)
C
C  IF STATION B IS EAST OF STATION A, A NEGATIVE SIGN IN THE "ABS VEL"
C  COLUMN IMPLIES A SOUTHWARD FLOWING CURRENT.
C
      WRITE (6,16)
      WRITE (6,18)
      N=N-1
      DO 62 I=1,N
   62 WRITE (6,17) SD(I),AVT(I),AMASST(I),ASALTT(I),AHEATT(I),XMSUM(I),S
     1SUM(I),TEMSUM(I)
      N=N+1
      I=N
      WRITE (6,17) SD(I),AVT(48),AMASST(48),ASALTT(48),AHEATT(48),XMSUM
     *(48),SSUM(48),TEMSUM(48)
      WRITE(6,1005)
 1005 FORMAT(11X,'BOTTOM')
      WRITE (6,1001)
 1001 FORMAT (' ',41X,'-----------',4X,'-----------',4X,'-----------')
```

```
      WRITE (6,1000) STMASS,STSALT,STHEAT
 1000 FORMAT('0',11X,'NET TOTALS',15X,3(F15.5))
      NNN=N
      WRITE(6,15)
      WRITE (6,14) VT,BASE  .
      WRITE(6,109)
  109 FORMAT(//13X,' TRANSPORTS BY WATER MASS TYPE')
      WRITE(6,110)BOTMAS,BOTSLT,BOTHT,CIRMAS,CIRSLT,CIRHT,AINMAS,
     1AINSLT,AINHT,CENMAS,CENSLT,CENHT,DEPMAS,DEPSLT,DEPHT,SUBMAS,
     2SUBSLT,SUBHT,SFCMAS,SFCSLT,SFCHT,UNKMAS,UNKSLT,UNKHT
  110 FORMAT(//19X,'WATERMASS',16X,'MASS',14X,'SALT',13X,'HEAT',
     1//17X,'A. A. BOTTOM      ',3F18.5,//15X,'A.A.CIRCUMPOLAR    ',
     23F18.5,//17X,'INTERMEDIATE      ',3F18.5,//16X,'S.ATL. CENTRAL    ',
     33F18.5,//21X,'DEEP',8X,3F18.5,//17X,'SUBANTARCTIC      ',3F18.5,
     4//19X,'SURFACE           ',3F18.5,//19X,'UNKNOWN            ',3F18.5)
      UPMAS=SFCMAS+CENMAS
      UPSLT=SFCSLT+CENSLT
      UPHT =SFCHT +CENHT
      HAFMAS=AINMAS+CIRMAS+SUBMAS+UNKMAS
      HAFSLT=AINSLT+CIRSLT+SUBSLT+UNKSLT
      HAFHT =AINHT +CIRHT +SUBHT+UNKHT
      DBMAS=DEPMAS+BOTMAS
      DBSLT=DEPSLT+BOTSLT
      DBHT =DEPHT +BOTHT
      WRITE(6,116)
  116 FORMAT(//13X,'TRANSPORTS BY EACH OF THREE LAYERS')
      WRITE(6,117)UPMAS,UPSLT,UPHT,HAFMAS,HAFSLT,HAFHT,DBMAS,DBSLT,DBHT
  117 FORMAT(//19X,'WATERMASS',16X,'MASS',14X,'SALT',13X,'HEAT',
     1//21X,'UPPER',7X,3F18.5,//20X,'MIDDLE',7X,3F18.5,//14X,'DEEP AND B
     2OTTOM',4X,3F18.5)
      STOT=UPMAS+HAFMAS+DBMAS
      STAT=UPSLT+HAFSLT+DBSLT
      STIT=UPHT+HAFHT+DBHT
      WRITE(6,1001)
      WRITE(6,131) STOT,STAT,STIT
  131 FORMAT(//18X,'SUB TOTAL',6X,3F18.5)
      IF (L .EQ. NGO) GO TO 120
      GO TO 70
  120 WRITE(6,114)
```

```
114  FORMAT('1',12X,'TOTAL TRANSPORTS')
     G=YY/NGC
     NH=NGC-1
     DO 2 I=1,NH
   2 YL(I)=I*G
     WRITE(06,4) YY,G,NGC
   4 FORMAT(2F10.3,I4)
     WRITE (6,109)
     WRITE (6,110) TBTMAS,TBTSLT,TBTHT,TCPMAS,TCRSLT,TCRHT,
    2TINMAS,TINSLT,TINHT,TCNMAS,TCNSLT,TCNHT,TDPMAS,TCPSLT,TDPHT,
    3TSBMAS,TSBSLT,TSBHT,TSFMAS,TSFSLT,TSFHT,TUNMAS,TUNSLT,TUNHT
     WRITE (6,116)
     TLPMAS=TCNMAS+TSFMAS
     TLPSLT=TCNSLT+TSFSLT
     TLPHT =TCNHT +TSFHT
     TAFMAS= TCRMAS+TINMAS+TSBMAS+TUNMAS
     TAFSLT= TCRSLT+TINSLT+TSBSLT+TUNSLT
     TAFHT = TCRHT +TINHT +TSBHT+TUNHT
     TDBMAS=TDPMAS+TBTMAS
     TDBSLT=TCPSLT+TBTSLT
     TDBHT =TDPHT +TBTHT
     WRITE(6,117)TUPMAS,TUPSLT,TUPHT,TAFMAS,TAFSLT,TAFHT,TDBMAS,
    1TDBSLT,TDBHT
     GTOT=TLPMAS+TAFMAS+TDBMAS
     GTAT=TLPSLT+TAFSLT+TDBSLT
     GTIT=TLPHT+TAFHT+TDBHT
     WRITE(6,1001)
     WRITE(6,119) GTOT,GTAT,GTIT
 119 FORMAT(//18X,'GRAND TOTAL       ',3E18.6)
     CALL IBCIEU( ABVEL,48,X,47,Y,NGC,XL,48,YL,NH,FL,48,WK,IER)
     CALL CONTUR    (FL,48,NGC,48,CL,-20,TITLE,18,12,LTG)
     CALL IBCIEU(BMASST,48,X,47,Y,NGC,XL,48,YL,NH,FL,48,WK,IER)
     CALL CONTUR    (FL,48,NGC,48,CL,-20,TITL1,18,12,LTG)
     CALL IBCIEU(BSALTT,48,X,47,Y,NGC,XL,48,YL,NH,FL,48,WK,IER)
     CALL CONTUR    (FL,48,NGC,48,CL,-20,TITL2,18,12,LTG)
     CALL IBCIEU(BHEATT,48,X,47,Y,NGC,XL,48,YL,NH,FL,48,WK,IER)
     CALL CONTUR    (FL,48,NGC,48,CL,-20,TITL3,18,12,LTG)
  70 RETURN
     END
```

BIBLIOGRAPHY

1. Angstrom, A. K., "Evaporation and precipitation at various latitudes and the horizontal eddy convectivity of the atmosphere," Arkiv for Matematik, Astronomi och Fysik, v. 20, 12 pp., 1925.

2. Baker, T. L., Mass, Salt and Heat Transport Across Seven Latitude Circles in the North Atlantic Ocean: A Description of the General Circulation Based on Geostrophic Calculations from International Geophysical Year and Adjacent Data, Master's Thesis, Naval Postgraduate School, Monterey, 1978.

3. Bennett, A. F., "Poleward Heat Fluxes in Southern Hemisphere Oceans," Journal of Physical Oceanography, v. 8, no. 5, 1978.

4. Bialek, E. L., Handbook of Oceanographic Tables, U. S. Naval Oceanographic Office, 1966.

5. Bjerknes, V.F.K., and others, Physicalische Hydrodynamic, Julius Springer, 1933.

6. Boisvert, W. E., Major Currents in the North and South Atlantic Oceans between 64°N and 60°S, Naval Oceanographic Office, TR-193, 1967.

7. Bryan, K., "Measurement of Meridional Heat Transport by Ocean Currents," Journal of Geophysical Research, v. 67, no. 9, pp. 3403-3414, 1962.

8. Budyko, M. I., N. Epinova, L. Zubenok, and L. Strokina, "The Heat Balance of the Earth's Surface," Izv. Akad. Nauk. SSSR, no. 1, 1962.

9. Budyko, M. I., The Heat Balance of the Earth's Surface, U. S. Department of Commerce, 1956.

10. Cummings, W. J., A Description of the General Circulation in the North Atlantic Ocean Based on Mass Transport Values Derived from IGY (1957-1958) Temperature and Salinity Data, Master's Thesis, Naval Postgraduate School, Monterey, 1977.

11. Defant, A., Die absolute Topographic des physisikalischen Meeresniveaus und der Druckflachen, sowie die Wasserbewegungen im Atlantischen Ozean. Wiss. Ergebn. D. Deutschen Atlantischen Exped. auf d. Forschungs - u. Vermessungsschiff 'Meteor'- 1925-1927, v. VI (2 Teil., 5 Leif.), Walter De Gruyter and Co., 1941.

12. Defant, A., Physical Oceanography, v. 1, Pergamon Press, 1961.

13. Emig, M., "Heat Transport by Ocean Currents," Journal of Geophysical Oceanography, v. 72, no. 10, 1967.

14. Ferrel, W., A Popular Treatise on the Winds, p. 163-164, Wiley, 1890.

15. Fomin, L. M., The Dynamic Method in Oceanography, pp. 117-148, Elsevier Publishing Co., 1964.

16. Fuglister, F. C., Atlantic Ocean Atlas of Temperature and Salinity Profiles and Data from the International Geophysical Year of 1957-1958, v. 1, Woods Hole Oceanographic Institution, 1960.

17. Fuglister, F. C., Gulf Stream '60, Ref. No. 64-4, Woods Hole Oceanographic Institution, Woods Hole, Mass., pp. 265-383, 1964.

18. Greeson, T. D., Mass, Salt, and Heat Transport Across 40°N Latitude in the Atlantic Ocean Based on IGY Data and Dynamic Height Calculations, Master's Thesis, Naval Postgraduate School, Monterey, 1974.

19. Haltiner, G. J. and Martin, F. L., Dynamic and Physical Meteorology, p. 13, McGraw-Hill, 1957.

20. Hidaka, K., "Depth of motionless layer as inferred from the distribution of salinity in the ocean," Trans. Am. Geophys. Union, v. 30, no. 3, 1940.

21. Ivers, W. D., The Deep Circulation in the North Atlantic, with Especial Reference to the Labrador Sea, Ph.D. Thesis, University of California, San Diego, 1975.

22. Iselin, C.O'D., "Preliminary report on long period variations in the transport of the Gulf Stream System," Papers in Physical Oceanography and Meteorology, no. 8, 1940.

23. Iselin, C.O'D., A Study of the Circulation of the Western North Atlantic, Papers in Physical Oceanography and Meteorology, 4, (4), 101 pp., 1936.

24. Jacobsen, J. P., "Contribution to the hydrography of the Atlantic," Medd. Komm. Havundersgelser, Ser. Hydrografi, v. 2, 1916.

25. Jung, G. H., "Note on the Meridional Transport of Energy by the Oceans," Journal of Marine Research, v. XI, no. 2, pp. 139-146, 15 Nov 1952.

26. Jung, G. H., Heat Transport in the North Atlantic Ocean, Ph.D. Thesis, The A.& M. College of Texas, College Station, TX, 1955.

27. Kimball, H. H., "Radiation Charts," Monthly Weather Review, v. 56, 1928.

28. Maury, M. F., The Physical Geography of the Sea, 6th ed., Harper, 1856.

29. Mazeika, P. A., "Eastward Flow within the South Equatorial Current in the Eastern South Atlantic," Journal of Geophysical Research, v. 73, no. 18, 1968.

30. McCartney, M. S., Worthington, L. V., and Schmitz, W. J., "Large Cyclonic Rings from the Northeast Sargasso Sea," Journal of Geophysical Research, v. 83, no. C2, pp. 901-914, 20 February 1978.

31. Model, F., "Berechnungsmethode fur die Uberfragung von Warme durch Wassermassen (Stromungen) unter verschiedenen physikalischen Bedingungen," Deutsche Hydrographische Zeitschrift, Unpublished Scientific Report No. 71, 1950.

32. Moroshkin, K. V., V. Bubnov, and R. Bulatov, "Water Circulation in the Eastern South Atlantic," Oceanology, v. 10, no. 1, pp. 27, 1970.

33. Neumann, G., Ocean Currents, Elsevier, 1968.

34. Neumann, G. and Pierson, W. J., Jr., Principles of Physical Oceanography, Prentice-Hall, pp. 244-247, 1966.

35. Newton, C. W., "Estimates of Vertical Motions and Meridional Heat Exchange in the Gulf Stream Eddies, and a Comparison with Atmospheric Disturbances," Journal of Geophysical Research, v. 66, 1961.

36. Parker, C. E., "Gulf Stream Rings in the Sargasso Sea," Deep-Sea Research, v. 18, pp. 981-993, 1971.

37. Parr, A., "Analysis of current profiles by a study of pycnomeric distortion and identifying properties," Journal of Marine Research, v. 4, 1938.

38. Richardson, P., "Gulf Stream Rings," Oceanus, v. 19, no. 3, pp. 65-68, 1976.

39. Robinson, A. R., "Eddies and Ocean Circulation," Oceanus, v. 19, no. 3, pp. 2-17, 1976.

40. Sellers, W. D., Physical Climatology, University of Chicago Press, 1965.

41. Sherfesee, L., Mass, Salt, and Heat Transport in the South Pacific, Master's Thesis, Naval Postgraduate School, Monterey, 1978.

42. Stommel, H., "On the determination of the depth of no meridional motion," Deep Sea Research, v. 3, pp. 273-278, 1956.

43. Stommel, H. and Schott, F., "The Beta Spiral and the determination of the absolute velocity field from hydrographic station data," Deep-Sea Research, v. 24, pp. 325-329, 1977.

44. Sverdrup, H. U., Johnson, M. W., and Fleming, R. H., The Oceans: Their Physics, Chemistry, and General Biology, Prentice-Hall, 1942.

45. Sverdrup, H. U., Oceanography, Handbuch der Physik, Springer Verlag, 1957.

46. Vander Haar, T. H. and Oort, A. H., "New estimates of energy transport by Northern Hemisphere oceans," Journal of Physical Oceanography, v. 3, no. 2, pp. 169-172, 1973.

47. Williams, J., Higginson, J. J., and Rohrbough, J. D., Sea and Air: The Marine Environment, 3d Ed., p. 189, Naval Institute Press, 1973.

48. Wust, G., "Bottom Water and the Distribution of the Deep Water of the Atlantic," Trans-340, U.S. Naval Oceanographic Office, Washington, 1967.

49. Wust, G., "Current Velocities, Deep and Bottom Waters," Trans-348, U.S. Naval Oceanographic Office, Washington, 1967.

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